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HAZARD AND ACCIDENT ANALYSIS

This chapter: (1) systematically identifies the potential hazards resulting from Waste Isolation Pilot Plant (WIPP) remote handled (RH) transuranic (TRU) waste disposal-phase handling and emplacement normal operations, and (2) assesses those hazards to evaluate abnormal, internal operational, external, and natural phenomena events that could develop into accidents. The hazard analysis: (1) considers the complete spectrum of accidents that may occur and qualitatively analyzes the accident annual occurrence frequency, and the resultant potential consequences to the public, workers, facility operations, and the environment; (2) identifies and assesses associated preventative and mitigative features for defense-in-depth; and (3) identifies a subset of accidents to be quantitatively evaluated in the accident analysis. The accident analysis evaluates these accidents against risk evaluation guidelines to verify the adequacy of the preventative and mitigative systems.

The methodology and requirements of 10 CFR Part 830.204,[1] and its implementing standards DOE-STD-1027-92[2] and DOE-STD-3009-94[3] were utilized in the development of this chapter. The potential hazards associated with the long-term waste isolation phase are addressed in the WIPP performance assessment submitted to EPA in October, 1996. The performance assessment is summarized in Section 5.3.

5.1 Remote Handled (RH) Transuranic (TRU) Hazard Analysis

The RH TRU 72-B cask and RH TRU 10-160B cask hazard analysis involved a multi-step process which included (1) identification of the potential hazards associated with RH waste handling operations, (2) characterization of the RH waste expected at the WIPP, (3) hazard evaluations in the form of Hazard and Operability Studies[4 &5] (HAZOPs) for the 72-B cask and 10-160B cask waste handling and emplacement processes, (4) the identification of potential accidents requiring quantitative accident analysis, (5) development of the defense-in-depth philosophy, and (6) an evaluation of worker protection from those accidents identified in the qualitative hazards analysis.

The hazard analysis in this section includes a thorough review of the following documentation; Final Environmental Impact Statement (FEIS),[6] Final Supplement Environmental Impact Statement (SEIS),[7] WIPP Fire Hazards and Risk Analysis (FHRA),[8] and Failure Modes and Effects Analyses to ensure hazards were thoroughly evaluated.

5.1.1 Hazard Identification

A hazard is defined as a material, energy source, or operation that has a potential for causing injury or illness in humans, or damage to a facility or the environment, without regard for the frequency or credibility of accident scenarios or consequence mitigation.[3] Hazards associated with normal WIPP operations include mining dangers, high voltage, compressed gases, confined spaces, radiological and non-radiological hazardous materials, non-ionizing radiation, high noise levels, mechanical and moving equipment dangers, working at heights, construction, and material handling dangers. Waste handling operations at the WIPP do not involve high temperature and pressure systems, rotating machinery, electromagnetic fields, or use of toxic materials in large quantities.

Routine occupational hazards are regulated by DOE-prescribed Occupational Safety and Health Act (OSHA) and by Mine Safety and Health Act (MSHA) standards. Programs for protecting WIPP workers from routine occupational hazards are discussed in Chapter 8.

As part of normal operations activities at the WIPP, the RH waste canisters (having met the WIPP RH Waste Acceptance Criteria[10] (RH WAC)) are inspected and surveyed for radiation, contamination, and damage before transfer to the Underground repository. Most significantly, the cleanliness of canisters is required to not be in excess of the DOE's free release limits in 10 CFR 835,[11] Occupational Radiation Protection, Appendix D prior to shipment from the generator sites. (See Chapter 7 for the basis for radiological and hazardous material protection limits.) WIPP normal operations do not entail any planned or expected releases of airborne radioactive materials which may present an internal occupational radiological hazard to workers, or present a hazard from the airborne pathway to the offsite public. Therefore, the radiological hazards for normal operations are limited to worker occupational external radiation exposure from the waste canisters. Non-radiological hazards to the public and worker during normal operations may result from small releases of Volatile Organic Compounds (VOCs) from waste canisters. Protection of the public and the worker from hazards involved with radiological and non-radiological materials during normal WIPP operations are discussed in detail in Chapter 7. Only that material contained in the waste containers is considered in establishing an inventory of radiological and non-radiological material, .

Operational, natural phenomena (such as earthquakes and tornadoes), and external hazards (such as aircraft crashes) are considered in this chapter when they are identified as an initiating event leading to an uncontrolled abnormal or accidental release of radiological or non-radiological materials from waste containers.

The external hazards presented by a natural gas pipeline explosion have been evaluated and are determined not to be a safety concern for the WIPP facility. Although significant localized heat, fire, and destruction result from such events, the nearest major gas pipeline to the Waste Handling building (WHB) is one mile away, and experience from recent occurrences indicates the explosion damage radius is a few hundred feet.

The hazards presented by the movement or mounting of pressurized gas cylinders used for alpha/beta counting systems in waste handling areas initiating an accident resulting in the release of waste container materials have been evaluated as being beyond extremely unlikely when the guidance provided in WP 12-IS.01, Industrial Safety Program[12], is adhered to.

For all conceivable operations and activities during the operational disposal-phase, few credible mechanisms can be identified that could lead to accidental releases of radiological and non-radiological hazardous materials. The RH waste containers are designed and fabricated in accordance with stringent regulatory requirements. The integrity of the waste containers is ensured during the design life in relation to the time interval of the disposal-phase. While accidents or incidents could occur to individual waste containers, the structural capabilities of the canisters and drums as designed can sustain anticipated waste canister drops of less than 4 ft (1.22 m) from waste handling equipment. In addition, WIPP waste handling operations do not entail any dispersal energies from high pressure, high temperature, or high energy systems that could result in breach of waste container integrity.

Additionally, it should be noted that the hazards identified as a result of WIPP operations, in relation to most high or moderate hazard nuclear facilities, do not require safe shutdown of the facility in a specific manner in terms of time and technical conditions. The WIPP facility and operations either individually, or collectively, can be shutdown or stopped at any time.

Inventory of Hazardous Materials

The hazard identification process resulted in identifying process operation locations within the WHB and the Underground disposal horizon for which an inventory of radiological material could be identified. The anticipated inventory was determined based on material form, location, and quantity associated with the process of receipt, handling, and disposal of RH TRU waste.

These process operation locations include:

1. Waste Handling Building
   - RH Bay
   - Cask Unloading Room (CUR)
   - Hot Cell
   - Transfer Cell
   - Facility Cask Loading Room
   - Conveyance Loading Room

2. Underground Horizon
   - Waste Shaft Station
   - Disposal Panel

Table 5.1-1 summarizes the maximum RH TRU waste canister inventory by facility process location. The radiological and non-radiological 72-B waste canister contents and the 10-160B cask contents are characterized in Section 5.1.2. The bounding radiological and non-radiological hazardous material inventory for each process location may be obtained by multiplying the number of 72-B waste canisters or the number of 10-160B casks by the maximum contents derived in Section 5.1.2.

5.1.2 RH Waste Characterization

This section describes the methodology used in the development of RH 72-B waste canister and 10-160B cask contents (radioactive/chemical content) to be disposed of at the WIPP. A description of 72-B waste canisters, 10-160B casks, types, volumes, radioactive and non-radioactive constituents, and discussions on content development are included for use in the hazards and accident analysis.

72-B waste canisters considered for this analysis are standard DOT Type A (or equivalent) canisters (maximum gross weight of 8,000 lb (3628.7 kg). The design of the canister is discussed in detail in Section 4.2.

The 10-160B cask meets the certification requirements for DOT Type B shipping containers (10 CFR 71.71-73) and has a maximum gross weight of 72,000 lb. The maximum total weight of the contents of a 10-160B cask is 14,500 lbs. including any shoring, waste drums, and optional insert.[13] The 55-gal drums in the 10-160B cask meet the certification requirements for DOT Type A shipping containers (49 CFR 178.350).

5.1.2.1 RH TRU Wastes

As defined in Public Law 102-579, WIPP Land Withdrawal Act,[14] the term "transuranic waste" means waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes per gram of waste, with half lives greater than 20 years, except for: a) high-level radioactive waste; b) waste that the Secretary has determined, with the concurrence of the Administrator, does not need the degree of isolation required by the disposal regulations; or c) waste that the Nuclear Regulatory Commission (NRC) has approved for disposal on a case-by-case basis in accordance with 10 CFR 61.

TRU waste is classified as either CH or RH, depending on the external dose rate at the waste container surface. RH TRU wastes are packaged with an external surface dose rate of up to 1000 rem/hr (10 Sv/hr). RH TRU waste decays principally by gamma and beta emission, with some alpha and neutron emissions. Alpha emitting radionuclides result in no external radiation exposure to humans, but are hazardous if inhaled or ingested. Since beta emissions, like alpha, have limited penetrating energy, adequate personnel protection is provided by the waste container. Gamma and neutron radiation are more penetrating, and require shielding for safe management and storage. RH TRU waste contains predominantly gamma and beta-emitting radioisotopes, and closed canisters provide protection from inhalation or ingestion.

5.1.2.1.1 RH TRU Radionuclide Inventory

The WIPP TRU Waste Baseline Inventory Report [17] (BIR), Revision 3, provides estimated volumes of RH TRU waste to be supplied by 9 DOE waste generator and/or storage sites. The radionuclide inventory by final waste form, stored waste volume, and waste site, as derived from a June 1996 query of Revision 3 of the BIR database, is shown in Table A-1 of Appendix A. Table A-2 shows the Pu-239 equivalent radioactivity (PE-Ci) of the radionuclides contained the RH TRU waste to be shipped to WIPP. (See Appendix B for a discussion on the PE-Ci concept). Table A-3 shows the radionuclide concentration in PE-Ci/canister for each RH waste generator site as well as the stored volume and equivalent number of canisters.

Revision 3 of the BIR[17] also provided new sampling data for the ORNL RH-TRU sludges, which showed that the primary uranium isotope present in these sludges is U-238 (not U-235, as reported in their previous Integrated Data Base (IDB) submittals). The uranium curies reported for RH-TRU waste in previous ORNL IDB submittals were redistributed based on the new sludge sampling data. This corrected the previously high estimates of U-235 in the ORNL RH-TRU waste inventory. DOE/CAO-95-1121[17] provides additional information about RH waste radionuclide inventory. Since approximately 96.5 percent of the total RH-TRU curies is contributed by Cs-137, Sr-90, Ba-137m, Pu-241, and Y-90, the remaining radionuclides contribute a very small fraction of the total curies for the repository.

The "Working Agreement for Consultation and Cooperation" (WACC)[15] limits the RH-TRU inventory to approximately 7,080 cubic meters (250,000 cubic feet) (DOE State of New Mexico, 1981), while the WIPP WACC for RH-TRU waste volumes and the WIPP Land Withdrawal Act[14] limit the activity of RH-TRU waste allowed in WIPP to 5.1 million curies and the activity concentration of RH waste to 23 Ci/liter (Public Law, 102-579)[16].

RH-TRU typically contains a greater proportion of fission and activation products that produce highly penetrating radiation and a higher level of radiation at the surface of the package than CH-TRU.

5.1.2.1.2 RH Radionuclide Inventory for Safety Analysis Calculations

Background

The establishment of a waste container radionuclide inventory (CI) for use in accident analysis calculations must involve: (1) an evaluation of existing safety analysis orders and guidance documents to establish the appropriate level of conservatism for the CI for safety analysis calculations; (2) consideration of the projected waste inventory listed in Appendix A, and the desire to encompass as much of the Pu-239 and Pu-238 waste as possible with the least design or operational impacts to both the waste generator and the WIPP; and (3) evaluation of the existing RH WAC[10] transportation constraints on nuclear criticality and Thermal Power criteria. The adequacy of the WIPP facility design, and operational administrative controls is evaluated in detail in Section 5.2.4.

Each Pu-mix will be scaled to the RH WAC[10] nuclear criticality limit of 325 fissile gram equivalent (FGE) for a RH 72-B waste canister and 200 FGE for a 55-gal drum in a 10-160B cask, using the isotopic weight distributions and converted to PE-Ci (see Appendix B for a discussion of the PE-Ci concept). Additionally, the maximum fissile loading will be no greater than 325 FGE per facility canister.

The 10-160B cask certification requirements, limit the decay heat from all drums in the cask to 100 watts per cask. The WIPP RH WAC Thermal Power transportation requirements, limit the decay heat from all RH-TRU waste to 300 watts per 72-B waste canister. However, based on previous discussions, for the predominant Pu-239 weapons grade operations waste, the most restrictive of the applicable WIPP RH WAC criteria is the nuclear criticality criterion, which restricts a single canister to 325 FGE.

Past WIPP safety analyses have established a waste container radionuclide inventory (CI) for use in accident analysis calculations based on inventory information from generator sites and on an average or representative content of a RH waste container. Discussions between DOE and the generator sites resulted in an agreement of plutonium-239 equivalent curies (PE-Ci) limits for the 72B canister. A 72B canister that contains direct loaded waste has a PE-Ci limit of 80 PE-Ci while a 72B canister that contains three 55-gal drums of waste (double confined waste) has a PE-Ci limit of 240 PE-Ci.

PE-Ci limits for the 10-160B cask of 20 PE-Ci are set in the NRC Certificate of Compliance.[13] A single drum (55 gal) in the 10-160B cask could contain up to 20 PE-Ci.

Approach for Developing the Waste Canister Radionuclide Inventory for Safety Analysis Calculations

RH 72-B cask waste shipments to the WIPP are comprised of a DOT Type A (or equivalent) canister per cask. Accident scenarios involve damage to the waste canister. Since the MAR for an accident scenario is a function of the number of waste canisters assumed damaged in the scenario and their individual radionuclide CI (MAR = CI * (number of containers damaged)), deriving a reasonable maximum for MAR must also involve deriving a reasonable maximum for CI, as well as the distribution of PE-Ci contents in the individual waste canisters assumed to be involved or damaged.

10-160B cask shipments to the WIPP meets the certification requirements for DOT Type B shipping containers. The drums in the 10-160B cask (maximum of 10) meet the certification requirements for DOT Type A (or equivalent) shipping containers. Accident scenarios involve damage to the 10-160B cask, its load (55-gal drums), or facility canister containing a maximum of three 55-gal drums from a 10-160B cask. Since the MAR for an accident scenario is a function of the number of 10-160B casks, 55-gal drums, or facility canisters assumed damaged in the scenario and their individual radionuclide CI (MAR = CI * (number of containers damaged)), deriving a reasonable maximum for MAR must also involve deriving a reasonable maximum for CI, as well as the distribution of PE-Ci contents in the individual 10-160B cask, drum, and facility canister assumed to be involved or damaged.

Based on the data in Appendix A, the average MAR in a waste canister is about 3.3 PE-Ci. The 72-B waste canister has a "bounding" inventory of either 80 PE-Ci (direct loaded canister) or 240 PE-Ci (loaded with three 55-gal drums). These values were selected to account for variations in the radionuclide content of the waste canisters. For the 10-160B cask, a "bounding" inventory of 20 PE-Ci for a 10-160B cask or a single 55-gal drum in the cask and 60 PE-Ci for a facility canister loaded with three 55-gal drums from three 10-160B casks.

The adequacy of these assumptions and the WIPP RH TRU facility design basis are evaluated in detail based on the accident results in Section 5.2.4. Receipt of waste for disposal at WIPP that does not meet the applicable Operations and Safety Requirements of the WIPP RH WAC will first require the performance of an Unreviewed Safety Question Determination (USQD) in accordance with the requirements of 10 CFR 830.203, Unreviewed Safety Question Process.[18]

5.1.2.2 TRU Mixed Waste

Hazardous waste, as defined in 40 CFR 261, Subparts C and D,[19] often occurs as co-contaminants with TRU waste from defense-related operations, resulting in TRU mixed waste. The BIR[17] estimates the quantities of Resource Conservation and Recovery Act (RCRA) regulated TRU waste to be shipped from each generator site. The most common hazardous constituents in the TRU mixed waste consist of the following:

<u>Metals</u>

Some of the TRU mixed waste to be emplaced in the WIPP facility contains metals for which toxicity characteristics were established (EPA hazardous waste codes D004 through D011). These materials are known to be present based on acceptable knowledge of waste-generating processes and various analytical results used to verify acceptable knowledge. Cadmium, chromium, lead, mercury, selenium, and silver are present in discarded tools and equipment, solidified sludges, cemented laboratory liquids, and waste from decontamination and decommissioning activities. A large percentage of the waste consists of lead lined glove boxes, leaded rubber gloves and aprons, lead bricks and piping, lead tape, and other lead items. Lead, because of its radiation-shielding applications, is the most prevalent metal present.

<u>Halogenated Volatile Organic Compounds</u>

Some of the mixed waste to be emplaced in the WIPP facility contains spent halogenated organic solvents (EPA hazardous waste numbers F001 through F005). The presence of these compounds is confirmed by analytical results from headspace gas sampling of TRU mixed waste. Methylene chloride; Tetrachloroethylene; trichloroethylene; carbon tetrachloride; 1,1,2-trichloro-1,2,2-trifluoroethane; and 1,1,1-trichloroethane (EPA hazardous waste codes F001 and F002) are the most prevalent halogenated organic compounds identified in TRU mixed waste that may be managed at the WIPP facility during the Disposal Phase. These compounds are commonly used to clean metal surfaces prior to plating, polishing, or fabrication; to dissolve other compounds; or as coolants. Because they are highly volatile, only very small amounts typically remain on equipment after cleaning, or in the case of treated wastewaters, in the sludges after clarification and flocculation.

Nonhalogenated Volatile Organic Compounds

Xylene, methanol, and n-butanol are the most prevalent non-halogenated VOCs in TRU mixed waste that may be managed at the WIPP facility during the Disposal Phase. These compounds occur in TRU mixed waste materials in much smaller quantities than halogenated VOCs. Like the halogenated VOCs, they are used as degreasers and solvents, and are similarly volatile. The same analytical methods that are used for halogenated VOCs are used to detect the presence of non-halogenated VOCs.

DOE Specific Processes and Activities

TRU mixed waste generated at DOE sites results from specific processes and activities that are well-defined and well-controlled, enabling the DOE to characterize waste streams on the basis of knowledge of the process and the raw materials used. Examples of the major types of operations that generate TRU mixed waste include:

Production of Nuclear Products - Production of nuclear products includes reactor operation, radionuclide separation/finishing, and weapons fabrication and manufacturing. The majority of the TRU mixed waste was generated by weapons fabrication and radionuclide separation and finishing processes. More specifically, wastes consist of residues from chemical processes, air and liquid filtration, casting, machining, cleaning, product quality sampling, analytical activities, and maintenance and refurbishment of equipment and facilities.

Plutonium Recovery - Plutonium recovery wastes are residues from the recovery of valuable plutonium contaminated molds, metals, glass, plastics, rags, salts used in electrorefining, precipitates, firebrick, soot, and filters.

Research and Development (R&D) - R&D projects include a variety of Hot Cell or glove box activities that often simulate full-scale operations described above, producing similar TRU mixed wastes. Other types of R&D projects include metallurgical research, actinide separations, process demonstrations, and chemical and physical properties determinations.

Decontamination and Decommissioning - Facilities and equipment that are no longer needed or usable are decontaminated and decommissioned, resulting in TRU mixed wastes consisting of scrap materials, cleaning agents, tools, piping, filters, Plexiglas™, glove boxes, concrete rubble, asphalt, cinder blocks, and other building materials. This is expected to be the largest category by volume of TRU mixed waste to be generated in the future.

Hazardous Constituents

Hazardous constituents in TRU mixed wastes to be shipped to the WIPP may exist in both the gaseous and solid states within the waste containers. For potential accident scenarios involving the breach of waste canister, knowledge of the hazardous materials in the gaseous state is necessary. Information on RH headspace gas concentrations is not available at this time and will not be available until the generator sites begin to package and characterize their RH waste. Therefore, information taken from the Hazardous Waste Facility Permit (HWFP)[20] for Contact Handled (CH) waste is assumed to be the same as for RH TRU and will be used in analyzing potential waste canister breach/puncture scenarios. (Headspace is the void surrounding the waste). This assumption is considered conservative because the total volume of RH waste will be less that five percent of the total TRU waste in the repository and the contribution of VOC's from RH may be minimal in relation to the contribution of VOC's from CH TRU.

Analytical data on the concentrations of 29 VOCs in the headspace gases has been calculated and is summarized in the HWFP, Table VI.D[20]. The most prevalent VOCs observed in the headspace gases are methylene chloride, chloroform, 1,1,2,2-tetrachloroethane, and carbon tetrachloride. Methylene chloride and carbon tetrachloride, and chloroform are considered potential carcinogens and require further analyses of the potential exposures during accident conditions. Methylene chloride, carbon tetrachloride, chloroform, and 1,1,2,2-tetrachloroethane are selected (due to prevalence) for consideration for accidental releases involving the release of headspace gases (Table 5.1-2).

Fire scenarios require knowledge of the hazardous materials in the solid/liquid state. The BIR,[17] indicates that the largest volume of existing TRU mixed waste is from the Idaho National Engineering and Environmental Laboratory (INEEL). The INEEL Hazardous Stored TRU Waste Source Term for the Radioactive Waste Management Complex Transuranic Storage Area[21] is used to develop the total waste container non-radioactive hazardous material inventory (Table 5.1-3).

The waste that will come to WIPP will be addressed by programs at the TRU waste generator sites that implement WIPP requirements. These programs will include the requirements of the Waste Analysis Plan (WAP) found in the HWFP, Chapter C.[20] The WAP defines the required waste characterization activities to be performed by the TRU waste generator sites. Every container of waste that will be shipped to WIPP will also meet the certification requirements contained in the WIPP RH WAC.[10] These criteria ensure that the waste is compatible with the transportation, management, and long-term disposal requirements for the WIPP.

The RH WAC [10] requires the generator to prepare a waste certification program that lists the methods and techniques used for determining compliance with the RH WAC [10] and associated quality assurance and quality control (QA/QC) criteria. The RH WAC [10] contains the health and safety based limits that the waste must meet for acceptance by WIPP. Also, the RH WAC [10] contains transportation related limits based on the Certificate of Compliance for the RH road casks (NRC) and for hazardous waste (EPA).

Waste Acceptance

Waste acceptance refers to the process whereby a final determination is made, on a container-by-container basis, that waste can be managed at WIPP in a manner that is protective of human health and the environment, and is in compliance with the regulations. Waste that is finally accepted for disposal at WIPP will have undergone the screening scrutiny required by WIPP programmatic documents. This means that waste must meet the requirements of the WIPP RH WAC[10] and Chapter C of the HWFP.[20] These programmatic documents require that data collected regarding the waste be verified at the point of generation, by the generating site project office, and then again by WIPP. The RH WAC establishes minimum criteria that the waste must meet, and limits that cannot be exceeded in order to maintain health and safety parameters. The following waste is unacceptable for management at the WIPP facility:

Ignitable, reactive, and corrosive waste

Liquid wastes (all waste must meet the RH WAC[10] criteria regarding residual liquid content)

Compressed gases

Incompatible waste (waste must be compatible with backfill, seal and panel closure materials, canister, road cask, facility cask, and as well as with other waste)

Headspace-gas VOC concentrations resulting in average annual emissions not protective of human health and the environment

Wastes with EPA codes not listed on HWFP, Table II.C. [20]

The WIPP facility will not accept waste that exhibits the characteristics of ignitability, reactivity, or corrosivity. The DOE ensures through administrative and operational procedures at the generator sites that TRU mixed waste received at the WIPP facility does not exhibit these characteristics. These characteristics are generally associated with liquid wastes or specific waste forms that may react violently. The HWFP, Chapter C,[20] and the RH WAC,[10] prohibit liquid waste, explosives, compressed gases, oxidizers, and pyrophorics. The prohibition of these materials is key to limiting the hazards associated with WIPP RH TRU waste handling activities.

The TRU mixed waste received at WIPP will not be aqueous or liquid, will not contain RH WAC prohibited materials, and will be capable of being handled at standard temperatures and pressures without reaction to oxygen or water. The RH WAC[10] specifies that liquid waste is not acceptable at WIPP. The WIPP facility will not accept RH casks holding waste that would be considered a liquid waste. Every 72-B canister holding waste shall contain less than 1.58 gal (6 L) of residual liquid. Every 10-160B drum (55-gallon) holding waste shall contain less than 0.53 gal (2L) of residual liquid. Each 72-B canister or 10-160B drum must contain as little residual liquid as is reasonably achievable.

Additionally, TRU mixed waste cannot contain explosives, compressed gases, oxidizers, or non-radionuclide pyrophoric materials. (Waste generators have submitted information on waste streams based on known waste generation processes that indicate certain waste streams may have the potential for reactivity, ignitability, or corrosivity.) These characteristics must be eliminated prior to waste acceptance for disposal at the WIPP.

The WIPP will manage TRU mixed waste in a manner that mitigates the buildup of explosive or flammable gases within the waste. Containers are vented through individual particulate filters, allowing any gases that are generated by radiolytic and microbial processes within a waste container to escape; to prevent over pressurization.

The WIPP facility is designed to manage only compatible waste. Therefore, a compatibility analysis was performed to identify potential incompatibilities for all defense generated TRU mixed waste reported in the BIR.[17] Wastes were screened for incompatibilities based on their chemical content and physical waste form. The compatibility analysis also took into account waste compatibility with various aspects of the repository such as shaft, seal, and panel closure materials, backfill, and fire suppressant materials.

To ensure the integrity of the WIPP facility, waste streams identified to contain incompatible materials or materials incompatible with waste canisters cannot be shipped to WIPP unless they are treated to remove the incompatibility. Only those waste streams that are compatible, or have been treated to remove incompatibilities, will be shipped to WIPP.

The DOE will only allow generators to ship those waste streams with EPA hazardous waste codes listed in Chapter A of the HWFP.[20] Characterization of all waste streams will be performed as required by the WAP. If during the characterization process, new hazardous waste codes are identified, those wastes cannot be accepted for disposal at the WIPP facility until a permit modification has been submitted and approved. Similar waste streams at other generator sites will be examined more closely to ensure that the newly identified code does not apply. If other waste streams also require a new hazardous waste code, shipment of these waste streams will also cease until a permit modification has been submitted and approved. Approval will be based on the physical and chemical properties of the waste.

The RH WAC requires the following information about the waste to be shipped to WIPP: radionuclide identification and quantities; confirmation of the waste form, identification, and indication that no excluded items have been detected; identification of the RCRA constituents identified from headspace gas analysis; totals analysis of homogeneous waste. The RH WAC also requests other information that is required for transportation, safe handling, and disposal of the waste.

5.1.3 RH Hazard Categorization

The hazard categorization for the RH TRU Waste Handling Process was developed based on the methodology and requirements in DOE-STD-1027-92,[2] which requires that a nonreactor nuclear facility be placed in a hazard category based on the unmitigated release of material from the facility. The material then is compared against threshold quantities (TQs) identified in Attachment 1 of DOE-STD-1027-92.[2]

The maximum RH waste container radionuclide inventory, developed in Section 5.1.2 and Table 5.1-1, susceptible to an unmitigated accidental release is 240 PE-Ci for the 72-B cask and 20 PE-Ci for the 10-160B cask. Since the 72B cask quantities exceed the Hazard Category 3 threshold of 56 Ci for Pu-239 (Attachment 1 of DOE-STD-1027-92[2]) the WIPP is classified overall as a Hazard Category 2 facility.

5.1.4 Hazard Evaluation

The WIPP RH TRU handling processes were qualitatively evaluated using HAZOPs [4 &5] (summarized in Appendix C). This systematic approach to hazard analysis is conducted by a leader knowledgeable in the HAZOP methodology, and consists of a team of personnel from various disciplines familiar with the design and operation of the RH TRU handling processes (HAZOP Team). The HAZOP Teams identified deviations from the intended design and operation of the waste handling system that could: (1) result in process slowdown or shutdown, (2) result in worker injury or fatality, and (3) result in the release of radiological and non-radiological hazardous materials from a waste canister.

The HAZOP Teams assigned a qualitative consequence and frequency ranking for each deviation. A hazard evaluation ranking mechanism utilized the frequency and the most significant consequences to separate the low risk hazards from high risk hazards that may warrant additional quantitative analysis. Based on this ranking approach, a basic set of accidents was chosen for further <u>quantitative</u> assessment in Section 5.2 to: (1) verify and document the basis for the qualitative frequency and consequence assignments in the HAZOP, and (2) identify the need for Design Class I (safety-class) structures, systems, or components (SSCs) and Technical Safety Requirements (TSRs).

The HAZOPs replace previous hazards analyses contained in documentation including the FEIS,[6] SEIS,[7] and WIPP FHRA,[8] for the purposes of identifying initiating events for quantitative accident analysis in Section 5.2. However, these documents were reviewed in preparation of this section, to ensure that all hazards associated with RH TRU waste handling were identified in the HAZOPs.

Since the performance of the HAZOPs for the RH waste handling processes, the WIPP Fire Hazard Analysis (FHA)[9] has been updated to incorporate both the 72B and 10-160B waste handling processes and to meet the requirements of DOE Order 420.1.[22]

The RH HAZOPs evaluated the WHB waste handling equipment fires, and fires associated with diesel powered waste handling equipment in the Underground as low frequency, low consequence events. Such fires may lead directly to waste handling equipment failure, or small fires impacting waste canisters, both of which may lead to a release of radionuclides. The updated FHA [9] investigated the increased potential for fires resulting from the introduction of the additional fuel and ignition source of the diesel powered vehicle in the waste panels.

5.1.4.1 HAZOP Methodology

The purpose of this study was to carefully review the RH TRU Waste Handling System and its operation in a systematic fashion to determine whether process deviations can lead to undesirable consequences. To meet this purpose, the HAZOP analysis technique was selected in accordance with guidance found in Figure 5.3 of Guidelines for Hazard Evaluation Procedures.[23]

The following characteristics relative to the RH 72-B and 10-160B waste handling processes analysis were identified:

- The results of the studies included specific accident situations plus safety improvement alternatives
- Both equipment failure and human error were evaluated
- The studies focused on single failure events
- The processes involved some relatively complex equipment operations
- The processes are not operating at the present, but relatively detailed design information is available.

An in depth description of the 72-B HAZOP can be found in Section 3.1 of DOE/WIPP-99-2303, Hazard Analysis Results Report for Remote Handled Waste,[4] while an in depth description of the 10-160B HAZOP can be found in Section 3.1 of WSMS-WIPP-00-0006, Hazard and Operability Study for the 10-160B Cask Remote Transuranic Waste Handling System (RH).[5]

Participant Selection

Support of these analyses included two levels of participation: (1) The Core Teams consisted of personnel from the WIPP facility and from Westinghouse Safety Management Solutions; and (2) Subject matter experts/consultants from the WIPP facility.

Core Teams - The HAZOP Core Teams (Team) were selected to provide experience in the HAZOP technique and to provide expertise in overall facility design, operation, and safety. The Team's tasks were to perform the major portion of the analysis, i.e., develop deviations, identify causes for those deviations, list consequences, identify safeguards, and recommend follow-up actions if the safeguards were judged to be inadequate. The individuals on both teams were full-time participants in the HAZOP processes.

Subject Matter Experts - Subject matter experts were identified to participate in the HAZOPs in the event that specific questions related to design or operation arose and more detailed information or answers were needed. These individuals were generally part-time participants but were available to participate as necessary.

Application of Technique

The first step in applying the HAZOP technique was to determine how the facility would be sectioned, i.e., identify the "study nodes". Because of the continuous flow characteristics of the process, the Team agreed that identifying study nodes in the form of process steps and specific functions of those steps would be appropriate and would facilitate identification of deviations. The study nodes or process steps and functions associated with 72B cask are shown in DOE/WIPP-99-2303[4], while those for the 10-160B cask are shown in WSMS/WIPP-00-0006[5].

The next step was to define the deviations from the intended function that could occur at each study node or process step. A combination of application of guide words and the knowledge based approach (see Section 3.1 of DOE/WIPP-99-2303[4] and WSMS-WIPP-00-0006[5]) was used to identify the deviations. The HAZOP Teams agreed that with the exception of the natural phenomena and external events for which specific frequencies had already been determined, event initiators would be considered to occur with a frequency in the "anticipated" range (see Table 5.1-4). The frequencies for the natural phenomena events and external events were listed as identified in DOE/WIPP-95-2065.[24] The deviations identified for each study node are listed in Appendix C.

Following identification of the deviations, causes and unmitigated consequences of those deviations were listed. As part of the qualitative determination of the consequences of each event, credit was taken initially only for the confinement and/or shielding expected to be provided by the road casks, the canisters, the drums, the facility cask, the Hot Cell and the WHB. No other preventive or mitigative features were assumed to be in place for determination of consequences.

The consequences that were listed for each deviation identified in the HAZOPs were then "ranked" qualitatively using two sets of criteria. The first ranking was a "total rank" which included both radiological and non-radiological consequences. This ranking process used a two number system consisting of a qualitative unmitigated consequence based on the criteria given in Table 5.1-5, and a frequency ranking based on the levels given in Table 5.1-4. As stated previously, the frequency for all event initiators, with the exception of natural phenomena and external events, was considered to be in the "anticipated" range. This resulted in the "total rank" which is recorded in Appendix C.

The "total" ranking for each deviation included both the resultant non-radiological and radiological consequences to the workers, the facility, and the offsite public. The possibility of worker fatality from a non-radiological accident resulted in the assignment of the highest possible consequence ranking of four. The purpose of this initial ranking was to provide an indication of those areas where there was a potential to improve the level of general industrial safety for facility workers.

The purpose of the second ranking was to identify those accidents that would pose the greatest radiological risk to the public, onsite workers, and the environment. This second ranking was based on the "radiological rank" consequence criteria given in Table 5.1-6. The radiological ranking was qualitatively estimated for each of three receptors: 1) the immediate worker, 2) the non-involved worker, and 3) the offsite maximally exposed individual (MEI).

The ultimate intent of the radiological ranking was to provide a means to select those potential accidents that would be of sufficient concern to be carried forward for quantitative accident analysis. For selection of candidate events for quantitative analysis, the consequences of each deviation were examined to focus only on risk posed by the accidental release of radiological material to the offsite individual. The results of this ranking are listed in Appendix C using the same two number system and format as that used for the total rank: consequence first, frequency second.

HAZOP Assumptions

The following assumptions were made for the HAZOP evaluation of RH waste handling operations:

- The WHB is designed adequately to withstand Natural Phenomena Hazards (NPH) events
- The WHB is Design Basis Earthquake (DBE) and Design Basis Tornado (DBT) qualified. [28]
- The RH bay outer doors will not be open when there are unsealed road casks containing RH TRU waste canisters/drums in the RH bay.
- The 140/25-ton crane in the RH Bay is qualified for DBE and DBT.[27]
- The Hot Cell is qualified for both DBE and DBT.
- The Hot Cell crane is DBE qualified. [27]
- Hot Cell shielding is designed for an internal gamma surface dose rate of 400,000 Rem/hr and for internal neutron surface dose rate of 45 Rem/hr. [26]
- The Hot Cell PAR® Manipulator is DBE qualified.
- Hot Cell concrete structure prevents fire from spreading into or out of the Hot Cell.
- The Transfer Cell will be maintained within the radiological control limits described in Appendix D of 10 CFR 835[11]. This means that if the Transfer Cell becomes contaminated during the RH waste handling process, operations will be stopped (when it is safe to do so) and will not resume until the room is decontaminated and once again meets the radiological control limits referenced above.
- There will be a catch pan (capacity of about 45 gal [170 L]) in the Facility Cask Loading Room to collect any hydraulic fluid that leaks from the equipment (reservoir capacity of 40 gal [151.4 L]).
- Fires that initiate in areas not defined as processing areas within the WHB will not have sufficient energy to propagate to areas defined as processing areas.[9]
- All RH waste that arrives at the WIPP site is in proper container and meets the RH WAC[10].
- Shipment of RH waste to the WIPP site is by truck only, not rail.
- Road casks have not been damaged in transit.
- Shielding will protect workers as designed.
- Industrial accidents are covered by MSHA and OSHA Industrial Safety programs.
- Deliberate unauthorized acts (e.g., sabotage) are addressed in the WIPP security program and therefore, are excluded from this analysis.
- There is no criticality concern related to the RH waste handling process. The waste material in a canister cannot shift into a configuration which could result in a criticality.
- No hazardous chemicals are used in the RH waste handling process.
- The hazardous chemical concentration including VOCs present in the RH waste is assumed to be the same as the hazardous chemical concentration present in the CH waste.[24] This assumption is used because there is no information available at this time for RH VOC concentrations.

- From a long term gas generation standpoint, RH waste is assumed to have the same composition as CH waste. Therefore, the hazardous gas generation rate for RH waste after panel closure will be the same as that for CH waste (0 - 0.04 moles/kg-yr with expected values of 0.02 moles/kg-yr)[30].
- The 72B casks meet the certification requirements for DOT Type B shipping containers (10 CFR 71.71-73[30]) and will withstand DBTs and explosions (maintain containment of contents).
- The 72 B canisters meet the certification requirements for DOT Type A (or equivalent) shipping containers.
- All 72-B canisters are vented; the vents will be functional under normal and abnormal conditions.
- There is no criticality concern related to disposal of 72B cask TRU waste at the WIPP site provided that the 72B waste canisters meet the following requirements:
  - The maximum fissile loading will be no greater than 325 grams per canister. [29]
  - The canister in the Transfer Cell will remain sub-critical under all normal and abnormal conditions.[29]
  - The 72B canisters are to be stored in horizontal positions in the walls of the Underground storage area. The boreholes shall not be placed any closer together than 30 inches center-to-center).[29]
- The exposure rate at the surface of an unshielded 72B canister will be no greater than 1000 rem/hr (10 Sv/hr).
- Verification of 72B canister identification in the Transfer Cell will be done remotely.
- The maximum radioactivity for the 72-B canister in terms of Pu-239 Equivalent Activity (PE-Ci) is 80 PE-Ci/canister for direct loading and 240 PE-Ci/canister for double contained RH waste (loaded with three 55- gal drums).
- The consequences of a radiological release from a RH 72-B waste canister are significantly greater than the toxicological consequences. Therefore, any toxicological consequences resulting from a release of material from a RH 72-B waste container are considered to be bounded by the radiological consequences.
- RH 72-B waste handling operations will be performed only in the areas described in Section 2.2 of DOE/WIPP-99-2303.[4]
- The 10-160B cask meets the certification requirements for DOT Type B shipping containers (10 CFR 71.71-73) and will withstand DBTs and explosions (maintain containment of contents). [13]
- Drains are located on the bottom of the 10-160B cask lower impact limiter such that no liquid can accumulate in that impact limiter.
- The drums (max 10) in the 10-160B cask meet the certification requirements for DOT Type A shipping containers (49 CFR 178.350).
- There is no criticality concern related to the 10-160B cask provided the mass limits of 10 CFR 71.53 [13] are not exceeded.
- The tools used to vent the 10-160B cask have HEPA filtration.
- It is assumed that the facility canister has an equivalent design to the 72B waste canister

- The exposure rate inside of one (1) 10-160B cask will be no greater than 1000 Rem/hr. For conservative analysis, it is assumed that one (1) drum contains all 1000 Rem/hr. Remaining drums contain none.
- There is no criticality concern related to disposal of 10-160B cask TRU waste at the WIPP site provided that the facility canister meets the following requirements:
  - The maximum fissile loading will be no greater than 325 grams per facility canister.
  - The facility canister in the Transfer Cell will remain sub-critical under all normal and abnormal conditions.[29]
  - The facility canisters are to be stored in horizontal positions in the walls of the Underground storage area. The boreholes shall not be placed any closer together than 30 inches, center-to-center.[29]
- The maximum radioactivity of one (1) 10-160B cask is 20 Pu-239 equivalent curies (PE-Ci). For events involving a breach of one (1) drum, it is assumed that all 20 PE-Ci are released.
- All drums in a 10-160B are vented; the vents will be functional under normal and abnormal conditions.
- Verification of 10-160B waste drums identification in the Hot Cell will be done remotely.
- The consequences of a radiological release from a 10-160B waste container (cask, facility canister or drum) are significantly greater than the toxicological consequences. Therefore, any toxicological consequences resulting from a release of material from a 10-160B waste container are considered to be bounded by the radiological consequences.
- 10-160B cask waste handling operations will be performed only in the areas described in Section 2.2 of WSMS-WIPP-00-0006.[5]
- Facility cask will shield 7,000 Rem/hr to 200 mrem/hr on contact. [25]
- The facility cask will maintain its containment and shielding function when dropped in a horizontal orientation from a height of 48 in (1.2 m).
- Based on the design features of the facility cask, it is assumed that the facility cask will maintain its structural integrity and containment function if it is impacted by the forklift or if it is involved in a collision with another vehicle while it is being transported by a forklift.
- RH storage locations are filled before CH waste is introduced to the disposal room.
- The exposure rate at the surface of a72-B cask , a 10-160B cask, or facility cask will be no greater than 200 mrem/hr (2 mSv/hr).[27]

HAZOP Results and Conclusions

The HAZOP Team reviewed the WIPP RH TRU Waste Handling System to identify hazards associated with the process, and deviations from the intended design and operation that could result in adverse consequences to the public, the worker, and the environment.

General areas of concern identified include:

Fires
Explosions
Internal and external conditions that may lead to a breach or rupture of the 10-160B cask, drums, facility canister and 72B waste canisters which could result in the airborne release of radiological materials.
Direct radiological exposure of personnel to high radiation and airborne radiological activity.
Worker injury or fatality.
External waste container surface contamination and need for decontamination.
Major damage to equipment and facility.
Major disruption of process operations.

The consequences of each deviation were developed without mitigating systems in place (with the exception of the confinement and/or shielding provided by the casks, canisters, and the WHB) and are listed in Appendix C. Appendix C also provides a listing, identified by the HAZOP Team, of the substantial safeguards currently existing at the WIPP facility to reduce the likelihood of the identified deviations and to mitigate the consequences of such deviations. Identified safeguards include design features such as radiation shielding, building structure, ventilation system, and casks; administrative control features such as procedures, worker training, preventive maintenance and inspection programs, and the WIPP RH WAC.[10]

5.1.4.2 Selection of RH Potential Accidents

To assess the relative radiological risk to the offsite individual, the frequency and radiological consequence rankings for that receptor were "binned" using the Risk Ranking Matrix given in Table 5.1-7. The resulting risk in each case was categorized as acceptable (having low risk), moderate, or high as defined on the matrix. Those deviations which had an offsite ranking with a frequency and consequence combination that is in the matrix area, or "bin", indicating low risk and concern were excluded from further consideration for quantitative evaluation. The events which impact the offsite public and have risk that falls in the darker shaded area on the risk matrix should be considered "situations of major concern" as described in DOE-STD-3009-94,[3] with sufficiently high risk that these events might be considered "unique" and individual examination might be used in the accident analysis phase. The events that impact the offsite individual and fall in the lighter shaded area in Table 5.1-7 are considered "situations of moderate concern" that yield a subset of "representative" events needing further examination. Representative events bound a number of similar events of lesser risk (the worst fire for a number of similar fires). At least one event from each of the event types is considered representative. Representative events are examined only to the extent that they are not bounded by unique events.

Table 5.1-8 lists the deviations considered to have a "radiological rank" which indicated moderate (lighter shaded area on Table 5.1-7) or high risk (darker shaded area on Table 5.1-7) to the offsite individual as determined by the binning process. The 17 hazardous events were selected as potential candidates for quantitative analysis. The frequency of an aircraft crash into WHB (hazardous event 13-7 in Table C-1) is beyond extremely unlikely based on the physical size of the WHB and the frequency of the flights within 5 miles of WIPP[24]. The consequences of the Underground Roof Fall[31] (hazardous event 14-1 in Table C-1) are negligible to the public and onsite worker, and low to immediate worker because of the storage location and design of the RH 72-B waste canister and the facility canister.

After examining the nature of the 17 individual hazardous events selected as candidates for quantitative analysis, and for minimization of repetitiveness, the events were grouped into "categories" of events with similar characteristics. The grouping resulted in 9 specific accidents (72-B) and 8 specific accidents (10-160B) that would be analyzed quantitatively. The accidents are listed in Table 5.1-9.

Following the ranking and binning process, applicable safeguards were identified for each event. Once the existing protection was identified, the adequacy of that protection was qualitatively judged. Based on the level of protection provided by the existing controls, follow-up items were listed in the form of Action Items or Recommendations. Action Items are those items which, in the judgement of the HAZOP Team, must be implemented to increase the safeguards or to verify the function of existing safeguards. Recommendations are those items which, in the judgement of the Team, would enhance the existing safeguards and must be addressed, but not necessarily implemented. Implementation of Recommendations is, however, strongly encouraged. The Action Items and Recommendations are summarized in Tables 8 and 9 respectively of DOE/WIPP-99-2303[4] and WSMS-WIPP-00-0006.[5]

5.1.5 Prevention of Inadvertent Nuclear Criticality

The intent of a criticality safety program is to prevent the accumulation of fissile and fissionable material and neutron moderating or reflecting materials in quantities and configurations that could result in an accidental nuclear criticality.

To ensure adequate margins of criticality safety for adherence to DOE O 420.1,[22] the WIPP facility was designed so that during each operation involving fissile material K_{eff} does not exceed a value of 0.947 (at the 95 percent probability level) for the most reactive set of conditions considered credibly possible. The calculation of K_{eff} includes the effect of neutron interaction and reflection between fissile elements and dimensional variations resulting from fabrication tolerances and changes due to corrosion and mechanical distortion. As discussed below, these calculations indicate the combination of conditions enabling the K_{eff} limit of 0.947 to be exceeded for the RH waste forms handled at the WIPP facility is incredible.

5.1.5.1 WIPP Nuclear Criticality Safety Program Elements

The WIPP nuclear criticality program elements consist of mass limits control, TRU waste disposal configuration control, and analytical verification of subcriticality.

Mass Limits Control

The WIPP RH WAC[10] limits the fissile or fissionable radionuclide content of RH TRU waste, including allowance for measurement errors, to 325 Fissile-Gram Equivalent (FGE) for a RH waste canister.

TRU Waste Disposal Configuration Control

In addition to the mass limits control, geometry controls are required for the emplacement and/or in-transit handling disposal configurations. Canisters will be stored in horizontal positions in the walls of the Underground disposal rooms with an analyzed minimum center-to-center spacing of 30 in (76 cm).[29]

RH TRU Nuclear Criticality Safety Analysis

In compliance with DOE O 420.1,[22] a criticality analysis[29] was performed to ensure that no credible criticality accident could occur at the WIPP. The analysis was based on the mass limit control and geometry control, with additional conservative assumptions in terms of; isotopic content, density and configuration modeling, moderation, and reflection. Further, for the RH waste analysis, it was assumed that the waste package storage array is infinite in both horizontal directions.

The results of the WIPP RH TRU criticality analysis[29] indicate that, for each of the conditions analyzed, the calculated effective multiplication factor, K_{eff}, is less than 0.95 including uncertainties at 95 percent probability at 95 percent confidence level. Accordingly, no credible criticality hazard exists at the WIPP for RH TRU operations.

DOE Order 420.1[22] requires additional analysis of nuclear criticality safety. The WIPP RH TRU criticality analysis [29] was examined for compliance with the order and all the applicable requirements for the order in performance of criticality analysis were complied with within the analysis.

5.1.5.2 Compliance with Mandatory ANSI/ANS Standards

The existing WIPP nuclear criticality safety program elements were reviewed to ensure compliance with the six mandatory American Nuclear Society ANSI/ANS nuclear criticality safety standards as the Order requires. The six mandatory standards are: ANSI/ANS-8.1,[32] 8.3,[33] 8.5,[34] 8.7,[35] 8.15,[36] and 8.19.[37]

The WIPP nuclear criticality safety program elements are found to be in compliance with the requirements of ANSI/ANS-8.1, Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors,[32] and ANSI/ANS-8.15, Nuclear Criticality Control of Special Actinide Elements,[36] in regard to: mass control, geometry control, and performance of criticality analyses.

The criticality-related administrative control provisions were determined to be in compliance with ANSI/ANS-8.19, Administrative Practices for Nuclear Criticality Safety.[37]

Since it has been established by analyses[29] that a criticality accident is beyond extremely unlikely (frequency $\leq$ 1 E-06/yr) at the WIPP, ANSI/ANS-8.3,[33] a Criticality Accident Alarm System, is not applicable as called for in the Order.

The two facility-specific standards, ANSI/ANS-8.5, Use of Borosilicate-Glass Raschig Rings as a Neutron Absorber in Solutions of Fissile Material,[34] and ANSI/ANS-8.7, Guide for Nuclear Criticality Safety in the Storage of Fissile Materials,[35] are not applicable to the WIPP.

The existing WIPP nuclear criticality safety program elements are in compliance with the DOE Order 420.1[22] mandatory criticality safety standards.

5.1.6 Defense-in-Depth

A defense-in-depth philosophy is employed in WIPP's approach to enhancing the safety of the facility in conjunction with its design and operations. The WIPP defense-in-depth safety approach provides layers of defense: (1) against release of radiological and non-radiological hazardous waste canister materials and the resultant consequences to the public and the environment, and (2) for protection of the worker against accidents. The WIPP approach provides three layers of defense against releases. Each successive layer provides an additional measure of the combined defense strategy.

The ultimate safety objective of the first, or primary layer of WIPP defense-in-depth is **accident prevention**. The reduction of risk (as the product of frequency and consequence) to both workers and the public from WIPP RH TRU waste handling and emplacement operations is primarily achieved by reducing the frequency of occurrence of postulated abnormal events or accidents. The conservative design of the facility's SSCs, with operations conducted by trained/qualified personnel to the standards set forth in approved procedures, provides the first layer. Specific preventative measures are identified in Appendix C for each postulated deviation as identified in the HAZOPs,[4,5] and in Table 5.1-10 for each deviation considered for quantitative accident analysis.

The occurrence frequency for each postulated deviation as identified in the HAZOPs,[4,5] and in Table 5.1-10 for each deviation considered for quantitative accident analysis, is primarily derived from the initiating event. To reduce the frequency of equipment failure, the facility design, fabrication, and construction will be undertaken in accordance with applicable codes and standards, based on the design classification of SSCs established in Chapter 4. Extensive pre-operational tests will be conducted to verify that SSCs perform their design function. This will be followed by in-service and pre-operational checks and inspections, and preventive maintenance and quality assurance programs.

The WIPP employs configuration management change control and modification retest to ensure quality throughout facility life. For hazards associated with underground operations, a substantial array of ground control planning and practices, support systems, instrumentation, monitoring, and evaluation exist to reduce the frequency of potential Underground accidents. Technical Safety Requirement (TSR) Administrative Controls (ACs) are derived in Chapter 6 and required in the WIPP TSR Document (Attachment 1 to the SAR) to ensure that the high level of design is maintained throughout the facility lifetime.

Additionally, as identified in the HAZOPs,[4,5] accident prevention for process inherent events, is achieved administratively through the RH WAC[10] which restricts waste elements (such as the presence of pyrophorics) which may be initiating events for accidents.

The following provide administrative controls to prevent the risk from postulated accidents from being unacceptable: (1) RH WAC limits on the radionuclide and fissile content of each waste canister, (2) waste canister integrity provisions ensure the robustness reflected in the waste canister accident release analyses, and (3) criticality safety is a designed in-storage and handling configuration that ensures (in conjunction with waste characteristics) that active criticality control is not required.

Prevention of human error as an initiating event is achieved by the extensive training and qualification programs, operational procedures, and conduct of operations programs. TSR ACs are derived in Chapter 6 and required in the WIPP TSR Document (Attachment 1 to the SAR) to ensure that these programs are maintained, and operations continue to be conducted with highly qualified and trained personnel using current approved procedures.

The second layer of defense-in-depth provides protection against anticipated and unlikely operational events that might occur in spite of the protection afforded by the first layer of defense. The second defense layer is characterized by detection and protection systems, and controls that: (1) indicate component, system, or process performance degradation created by compromises of the first layer, and (2) provide adequate mitigation and accommodation of the consequences of those operational accidents which may occur.

Specific mitigative features are identified in Appendix C for each postulated deviation as identified in the HAZOPs,[4,5] and in Table 5.1-10 for each deviation considered for quantitative accident analysis. In general, the WHB and underground radiation and effluent monitoring systems and HEPA filtration systems, and the WIPP Emergency Management Program[38] provide this layer of defense-in-depth. In addition, the WIPP Human Factors Evaluation,[39] determined that well established policies and procedures are in place ensuring normal and emergency procedures are implemented, adequate directions have been provided to shift personnel concerning actions to be taken in a potential accident environment, and adequate procedures are available for follow up response. TSR ACs are derived in Chapter 6 and required in the WIPP TSR Document (Attachment 1 to the SAR) supporting the second level of defense-in-depth. Programs supporting defense-in-depth as required by the TSRs, are discussed in Chapters 7, 8, and 9.

The third layer of defense-in-depth supplements the first two layers by providing protection against extremely unlikely operational, natural phenomenon, and external events. These events represent extreme cases of failures and are analyzed in Section 5.2.3 using conservative assumptions and calculations to assess the radiological and non-radiological effects of such accidents on the MEI, non-involved worker, and immediate worker to verify that a conservative design bases has been established. These accidents include fire, waste hoist failure, and breach of waste container.

5.1.7 Protection of Immediate Workers from Accidents

The RH HAZOPs [4,5] identified a number of waste handling process hazards that could potentially lead to events resulting in immediate worker injury or fatality, or exposure to radiological and non-radiological hazardous materials. The Total Rank (or risk) for each postulated deviation as identified in Appendix C, is the qualitative product of the frequency of the event and the potential consequences. As shown in Appendix C, the consequences of the postulated deviations were dominated by the assumption that a worker fatality may result without safeguards in place, regardless of dose or dosage received.

Consistent with: (1) 10 CFR 830.205, Technical Safety Requirements;[40] (2) the defense-in-depth philosophy discussed in Section 5.1.6; and (3) the philosophy of Process Safety Management (PSM), as published in 29 CFR 1910.119, Process Safety Management of Highly Hazardous Chemicals,[41] reduction of the risk to workers from accidents is accomplished at the WIPP primarily by identifying controls to **prevent the event from happening**. (note: Compliance with 29 CFR 1910.119 is not required by WIPP. However, the WIPP philosophy of reduction of accident risk is consistent with this standard.) The TSRs are not based upon maintaining worker exposures below some acceptable level following an uncontrolled release of hazardous material or inadvertent criticality; rather the risk to workers is reduced through the reduction of the frequency and potential impact of such events.

Consistent with this statement, in conjunction with the defense-in-depth philosophy, total risk is evaluated by: (1) performing engineering analyses in the form of event tree/fault tree analysis to identify systems, structures, components, processes, or controls that contribute most to the accident phenomena frequency for the purposes of verifying their adequacy or identifying improvements to reduce the accident frequency and therefore risk, and (2) evaluating human error as an initiating event.

As discussed in Section 5.1.4.1, the HAZOP Teams identified a significant number of existing preventative safeguards that lower the frequency of occurrence of each deviation, substantially reducing the risk of injury or fatality to workers. The HAZOP Teams concluded, consistent with the first layer of defense-in-depth, that safeguards currently exist at the WIPP to prevent or reduce the frequency of such deviations from occurring. Identified preventative safeguards shown in Appendix C, and Table 5.1-10 include the following:

- Facility and equipment design, application of appropriate design classification and applicable design codes and standards,
- Programs relating to configuration and document control, quality assurance, and preventative maintenance and inspection,
- Administrative controls including the WIPP RH WAC,[10] waste handling procedures and training, and the WIPP Emergency Management Program[38] and associated procedures.

Section 5.2.3 evaluates the accident dose consequences to immediate workers from operational waste handling accidents whose frequency is greater than 1E-06/yr, and may be initiated by waste handling equipment failure or directly through human error by a worker performing a waste handling operation. These accidents include crane failure, and waste canister drops in the WHB and the Underground. The immediate worker is that individual directly involved with the waste handling operation for which the accident is postulated. This evaluation will ensure that the maximum allowable radionuclide inventory, in conjunction with the other layers of defense-in-depth, will preclude worker exposure from being unacceptable. Releases from such accidents are conservatively assumed to be instantaneous and, although procedures dictate that workers exit the area immediately, such accidents present an immediate risk due to the inhalation of airborne radionuclides to the worker performing the waste handling operation.

To evaluate the risk to immediate workers from extremely unlikely operational accident, such as waste hoist failure, the direction of resources in this SAR is more focused on the evaluation of system/facility reliability (accident prevention) than on an in-depth evaluation of radiological consequences to an immediate worker and post accident mitigative systems and controls. This evaluation is conducted in the event tree/fault tree analysis in Appendix D, and the accident scenario and evaluation of design adequacy descriptions for each applicable accident in Section 5.2.3. In addition to these fault tree analyses, human error as an initiating event is evaluated in the WIPP Human Factors Evaluation.[39]

As derived from the RH HAZOPs, the risk to immediate workers from severe natural phenomenon (DBE and/or DBT), is dominated by worker fatality due to the energetic phenomenon during the event, as opposed to a specified radiological dose for which additional mitigative SSCs or administrative controls may be derived. This SAR is focused more on the evaluation of the existing facility design when subjected to the severe natural phenomenon (to reduce the likelihood of worker fatality, as well as breach of waste containers), rather than on the evaluation of radiological consequences to an immediate worker. This evaluation is conducted in the accident scenario and evaluation of design adequacy descriptions for each applicable accident in Section 5.2.3.

The RH waste operations hazardous events that only exceed the immediate worker criteria are shown in Table 5.1-11. Other hazardous events that exceed offsite criteria are analyzed in the accident analysis as previously described. It is estimated that either there are no consequences or the mitigated consequences are below the anticipated guideline of 5 rem (50 mSv) per year after crediting (qualitatively) the preventive and/or mitigative features.

5.1.8 Defense-in-Depth Structures, Systems, and Components (SSCs)

Specific preventative and mitigative SSCs are listed in Appendix C for each postulated deviation as identified in the HAZOP,[4,5] and in Table 5.1-10 for each deviation considered for quantitative accident analysis. Specific SSCs that fulfill a defense-in-depth function, or are considered essential for waste handling, storage and/or disposal operations are as follows: (1) WHB Heating, Ventilation and Air Conditioning (HVAC) (excluding CH area ventilation), and Underground Ventilation and Filtration System (UVFS) (including underground shift to filtration); (2) Waste Hoist Equipment (including Brake System designated Safety Significant from the CH SAR); (3) Waste Handling Equipment (including the grapple hoist, RH cranes, etc., as required), (4) WHB structure including tornado doors, (5) Central Monitoring System (to support underground shift to filtration only); and (6) Radiation Monitoring System, active waste disposal room exit alpha CAM (for underground shift to filtration).

Section 5.2.4.1, Evaluation of the Design Basis, discusses in detail: (1) the evaluation of safety SSCs, and (2) the applicability of functional and performance requirements (system evaluation) and controls (TSRs). Detailed design descriptions for the above SSCs may be found in the applicable system design descriptions (SDDs) as referenced in Chapter 4.

References for Section 5.1

1. 10 CFR 830.204, Documented Safety Analysis.

2. DOE-STD-1027-92, Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports, 1992.

3. DOE-STD-3009-94, Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports, July 1994.

4. WP 02-RP.02, Hazard Analysis Results Report for Remote Handled Waste (RH), Waste Isolation Pilot Plant, July 1999.

5. WSMS-WIPP-00-0006, Hazard and Operability Study for the 10-160B Cask Remote Transuranic Waste Handling System (RH), Waste Isolation Pilot Plant, Westinghouse Safety Management Solutions, January 2001.

6. DOE/EIS-0026, Final Environmental Impact Statement, Waste Isolation Pilot Plant, 2 Vols, U.S. Department of Energy, Carlsbad, N.M., 1980.

7. DOE/EIS-0026-FS, Final Supplement Environmental Impact Statement, Waste Isolation Pilot Plant, U.S. Department of Energy, Carlsbad, N.M., 1990.

8. DOE/WIPP 91-031, WIPP Fire Hazards and Risk Analysis, May 1991.

9. DOE/WIPP-3217, WIPP Fire Hazards Analysis Report, June 2002.

10. DOE/WIPP-Draft 3123, RH TRU Waste Acceptance Criteria for the Waste Isolation Pilot Plant.

11. 10 CFR 835, Occupational Radiation Protection

12. WP 12-IS.01, Industrial Safety Program

13. Safety Evaluation Report Model CNS 10-160B Package Certificate of Compliance No. 9204, Revision No. 5, U.S. Nuclear Regulatory Commission, May 2000.

14. Public Law 102-579, WIPP Land Withdrawal Act, October 1992.

15. Working Agreement for Consultation and Cooperation Between Department of Energy and the State of New Mexico on the Waste Isolation Pilot Plant, April 1988.

16. Public Law 102-386, Federal Facility Compliance Act, U.S. Congress, 1992.

17. DOE/CAO-95-1121, U.S. Department of Energy Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report (BIR), Revision 3, June 1996.

18. 10 CFR 830.203, Unreviewed Safety Questions.

19. 40 CFR 261, Identification and Listing of Hazardous Waste.

20. Hazardous Waste Facility Permit No. NM4890139088-TSDF, issued by the New Mexico Environment Department October 27, 1999.

21. ENV-003, Hazardous Stored TRU Waste Source Terms for the RWMC's TSA, 1990.

22. DOE O 420.1, Facility Safety, October 1995.

23. Guidelines for Hazard Evaluation Procedures, Second Edition, Center for Chemical Processing Safety of the American Institute of Chemical Engineers, 1992.

24. DOE/WIPP-95-2065, Rev.4, Waste Isolation Pilot Plant Safety Analysis Report, January 2000.

25. Statistical Summary of Radiological Base for WIPP, DOE/WIPP 42-037, 1992.

26. System Design Description, SDD CFOO-GC00.

27. System Design Description, SDD WH03.11-1.

28. System Design Description, SDD General Plant Description

29. Waste Isolation Pilot Plant Nuclear Criticality Safety Evaluation for Remote Handled Waste (U), WSMS-WIPP-00-0003, Rev. 1, December 2001.

30. 10 CFR 71.71-73, Packaging and Transportation of Radioactive Material

31. PLG-1167, Analysis of Roof Falls and Methane Gas Explosions in Closed Rooms and Panel

32. ANSI/ANS-8.1, Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors.

33. ANSI/ANS-8.3, Criticality Accident Alarm System.

34. ANSI/ANS-8.5, Use of Borosilicate-Glass Raschig Rings as a Neutron Absorber in Solutions of Fissile Material.

35. ANSI/ANS-8.7, Guide for Nuclear Criticality Safety in the Storage of Fissile Materials.

36. ANSI/ANS-8.15, Nuclear Criticality Control of Special Actinide Elements.

37. ANSI/ANS-8.19, Administrative Practices for Nuclear Criticality Safety.

38. WP 12-9, WIPP Emergency Management Program.

39. WP 02-RP.03, WIPP Human Factors Evaluation, May 2002.

40. 10 CFR 830.205, Technical Safety Requirements.

41. 29 CFR 1910.119, Process Safety Management of Highly Hazardous Chemicals.

Table 5.1-1 Maximum Hazardous Material Inventory by Facility Location

Hazard Type	Material Form	Location (Facility Process)	Inventory: Number of Canisters	Basis for Number of Canisters
WASTE HANDLING BUILDING (72-B Cask)				
Radioactive/Non-radioactive Material	RH TRU Waste	RH Bay	2	2 72B casks processed at a time[1]
		Transfer Cell	1	1 road cask processed at a time
		Facility Cask Loading Room	1	1 facility cask processed at a time
UNDERGROUND HORIZON (72-B Cask)				
Radioactive/Non-radioactive Material	RH TRU Waste	Waste Shaft Station	1	1 Facility cask processed at a time
		Disposal panel	730	Total waste capacity/panel
WASTE HANDLING BUILDING (10-160B Cask)				
Radioactive/Non-radioactive Material	RH TRU Waste	RH Bay	20 drums	2 10-160B casks processed at a time[1]
		Hot Cell	6 loaded canisters + 10 drums = 28 drums	
		Transfer Cell	1	1 facility canister processed at a time
		Facility Cask Loading Room	1	1 facility cask processed at a time
UNDERGROUND HORIZON (10-160B Cask)				
Radioactive/ Non-radioactive Material	RH TRU Waste	Waste Shaft Station	1	1 Facility cask processed at a time
		Disposal panel	730	Total waste capacity/panel

Notes:
1. Any combination of two 10-160B and 72-B casks can be processed in the RH Bay of the WHB.

Table 5.1-2 VOC Concentrations

Chemical	Weighted[1] Average (ppmv/mole gas)	Mole Fraction (1.0E-06 mole VOC/ppmv)	Moles gas/canister or drum (moles gas)[3]	Molecular Weight (g/mole)	Unit Conversion 2.2E-03 lb/g (1.0E+03mg/g)	Canister or Drum Inventory[2] lb (mg)
72-B Canister						
Methylene Chloride	368.5	1.0E-06	28.38	84.9	2.2E-03 (1.0E+03)	2.0E-03 (887.9)
Chloroform	25.3	1.0E-06	28.38	119.4	2.2E-03 (1.0E+03)	1.9E-04 (85.7)
1,1,2,2-Tetrachloroethane	9.4	1.0E-06	28.38	167.9	2.2E-03 (1.0E+03)	9.9E-05 (44.8)
Carbon Tetrachloride	375.5	1.0E-06	28.38	153.8	2.2E-03 (1.0E+03)	3.6E-03 (1639.0)
10-160B Cask						
Methylene Chloride	368.5	1.0E-06	6.5	84.9	2.2E-03 (1.0E+03)	4.5E-04 (2.0E+02)
Chloroform	25.3	1.0E-06	6.5	119.4	2.2E-03 (1.0E+03)	4.3E-05 (2.0E+01)
1,1,2,2-Tetrachloroethane	9.4	1.0E-06	6.5	167.9	2.2E-03 (1.0E+03)	2.3E-05 (1.0E+01)
Carbon Tetrachloride	375.5	1.0E-06	6.5	153.8	2.2E-03 (1.0E+03)	8.3E-04 (3.8E+02)

Notes:

1. Data from Hazardous Waste Facility Permit [15].
2. Canister Inventory = weighted average (ppmv VOC/mole gas) x mole fraction (1E-06 mole VOC/ppmv VOC) x moles gas/canister (28.38 moles gas at STP/canister) x molecular weight (g/mole VOC) x (2.2E-03 lb/g)
   Assumption: 70% void space in TRU waste canisters
   240 gallons waste canister at STP: air =0.01076 lbs/gallon; molecular weight air = 0.06372 lbs/mole
   55 gallon waste drum at STP: density of air = 0.01076 lbs/gallon
   Air moles/gal = (0.01076 lbs/gallon)/(0.06372 lbs/mole) = 0.1689 mole/gallon
   Moles gas /canister = (0.70)(240 gallons/canister)(0.1689 mole/gallon) = 28.38 moles/canister
   Moles gas /drum = (0.70)(55 gallons/drum)x (0.01076 lbs/gallon/0.06372 lbs/mole) = 6.5 moles/drum
3. Drum inventory = weighted average (ppmv VOC/mole gas) x mole fraction (1.0E-06 mole VOC/ppmv VOC) x moles gas/drum (6.5 moles of gas at STP/drum) x molecular weight (g/mole) x unit conversion factor

Table 5.1-3 Hazardous Material Concentrations Used in Analysis

Chemical	Average[1] Weight Fraction	Inventory - lbs (mg)[2] (Based on 6300 lbs/ 72-B canister)	Inventory - lbs (mg)[3] (Based on 243 lbs/drum)	Total 10-160BCask Inventory - mg	Inventory in One Drum - mg (Based on 10 drums per cask)
Asbestos	2.7E-03	17.00 (7.7E+06)	6.6E-01 (3.0E+05)	3.0E+06	3.0E+05
Beryllium	2.1E-04	1.32 (6.0E+05)	5.1E-02 (2.3E+04)	2.3E+05	2.3E+04
Cadmium	3.0E-06	1.9E-02 (8.6E+03)	1.0E-03 (3.3E+02)	3.3E+03	3.3E+02
Lead	8.3E-03	52.3 (2.4E+07)	2.0E+00 (9.2E+05)	9.2E+06	9.2E+05
Butyl Alcohol	3.0E-03	18.9 (8.6E+06)	7.3E-01 (3.3E+05)	3.3E+06	3.3E+05
Carbon Tetrachloride	6.3E-03	39.7 (1.8E+07)	1.5E+00 (6.9E+05)	6.9E+06	6.9E+05
Mercury	3.5E-03	22.05 (1.0E+07)	8.5E-01 (3.9E+05)	3.7E+06	3.7E+05
Methyl Alcohol	8.0E-06	5.0E-02 (2.3E+04)	2.0E-03 (8.8E+02)	8.8E+03	8.8E+02
Methylene Chloride	4.0E-04	2.5 (1.1E+06)	9.7E-02 (4.4E+04)	4.4+05	4.4E+04
Polychlorinated Biphenyl (PCB)	8.5E-03	53.55 (2.4E+07)	2.1E+00 (9.4E+05)	9.4E+06	9.4E+05
Trichlorethylene	3.9E-03	24.6 (1.1E+07)	9.5E-01 (4.3E+05)	4.3E+06	4.3E+05

Notes:

1. Data from Reference 16, Table 1. Data listed is average weight fraction of each hazardous material of the <u>total</u> canister/drum weight. Sum will not add to unity, as other nonhazardous materials are within each canister and or drum.
2. Canister Inventory = (Weight Fraction) x (6300 lbs/canister) [x (453.592 g/lb) x (1E+03 mg/g)]
3. Cask Inventory = (Weight Fraction) x (2430 lbs/cask) [x (453.592 g/lb) x (1000 mg/g)]

Table 5.1-4 Initiating Frequency Evaluation Levels

Rank	Frequency Code	Description	Estimated Frequency of Occurrence (yr^{-1})
4	Anticipated (A)	Accidents that may occur several times during the lifetime of the facility (accidents that commonly occur).	$10^{-1} \geq$ frequency$>10^{-2}$
3	Unlikely (U)	Accidents that are not anticipated to occur during the lifetime of the facility (e.g., Uniform Building Code-level earthquake, 100-year flood, maximum wind gust).	$10^{-4} < f \leq 10^{-2}$
2	Extremely Unlikely (EU)	Accidents that will probably not occur during the life cycle of the facility. This includes the design basis accidents.	$10^{-6} < f \leq 10^{-4}$
1	Beyond Extremely Unlikely (BEU)	All other accidents.	$f \leq 10^{-6}$

Table 5.1-5 Qualitative Total Consequence Classification and Rank

Consequence Rank	Descriptive Word	Description
4	High	May cause death to facility workers from an industrial accident. Considerable offsite impact to people and environs. Offsite contamination requiring cleanup; or facility destruction.
3	Moderate	May cause severe facility worker injury with disability from an industrial accident. Minor offsite impact to people or environs. May result in facility contamination, or facility damage with considerable disruption of facility operations; or considerable onsite impact to people or the environs.
2	Low	May cause minor facility worker injury as the result of an industrial accident or acute exposure from radiological material with lost time and with no disability. Negligible offsite impact to people or environs. May result in facility contamination, or facility damage with minor disruption of facility operation.
1	Negligible	Negligible onsite and offsite impact on operations, people or environs. May cause minimal impact to facility worker injury as the result of an industrial accident or acute exposure to radiological material with no lost time. May result in minimal facility contamination with negligible disruption of facility operations.

Table 5.1-6 Qualitative Radiological Consequence Classification and Rank

Consequence Rank	Descriptive Word	Description
4	High	Considerable offsite impact to people and environs. Offsite contamination requiring cleanup; or facility destruction.
3	Moderate	Minor offsite impact to people or environs. May result in facility contamination, or facility damage with considerable disruption of facility operations; or considerable onsite impact to people or the environs.
2	Low	May cause minor facility worker injury as the result of an acute exposure from radiological material with lost time and with no disability. Negligible offsite impact to people or environs. May result in facility contamination, or facility damage with minor disruption of facility operation.
1	Negligible	Negligible onsite and offsite impact on operations, people or environs. May cause minimal impact to facility worker as the result of acute exposure to radiological material with no lost time. May result in minimal facility contamination with negligible disruption of facility operations.

Table 5.1-7 Risk Binning Matrix

CONSEQUENCES

FREQUENCY	Negligible (1)	Low (2)	Moderate (3)	High (4)
Anticipated (4) $10^{-1} \geq f > 10^{-2}$				
Unlikely (3) $10^{-4} < f \leq 10^{-2}$				
Extremely Unlikely (2) $10^{-6} < f \leq 10^{-4}$				
Beyond Extremely Unlikely (1) $f \leq 10^{-6}$				

Situations of high risk and major concern; may be considered as "unique" events; candidates for individual examination

Situations of moderate risk and concern; representative events; examine bounding events

Situations of little risk and concern; no accident analysis needed

Table 5.1-8 Summary of Hazardous Events Selected for Quantitative Analysis **Page 1 of 2**

72-B Cask			
Major Concern		**Moderate Concern**	
Study Node/Event	**Deviation**	**Study Node/Event**	**Deviation**
7-1	Shuttle moves while crane is lifting canister	10-5	Shield valve on emplacement equipment is closed on canister
7-2	Canister dropped while being lifted into facility cask	10-6	Mis-alignment of canister as it is moved into borehole
7-6	Shield valves (2) close on canister	13-1	Seismic Event (Design Basis Earthquake)
7-10	Hydraulic fluid fire	13-2	Tornado (Design Basis Tornado)
8-4	Conveyance positioned at station, facility cask dropped into shaft		
8-6	Loss of brakes on conveyance while loaded with facility cask - conveyance drops to bottom of waste shaft		
9-5	Forklift drops facility cask		
9-7	Diesel fire on forklift		
9-8	Diesel fire followed by an explosion		
10-1	Loss of control - Forklift drops facility cask onto emplacement equipment		
10-2	Hydraulic fluid/diesel fuel fire		
10-3	Hydraulic/diesel fuel fire followed by an explosion		

Table 5.1-8 Summary of Hazardous Events Selected for Quantitative Analysis Page 2 of 2

10-160B Cask			
Major Concern		**Moderate Concern**	
Study Node/Event	**Deviation**	**Study Node/Event**	**Deviation**
1B-6	While moving compressed gas cylinders in RH Bay, cylinder falls - ruptures and impacts cask.	10BF-1	While lifting the drum, drop drum in the Hot Cell.
4D-1	Cask falls off of RCTC in RH Bay while lid is loose.	11D-1	Fire in the Hot Cell.
4F-1	Shield plug dropped onto stored facility canister in Hot Cell.	11D-2	Explosion in the Hot Cell.
4G-1	Cask lid dropped onto the cask and drums in CUR.	11D-3*	Halogenated hydrocarbons accumulate in facility canister head space and welding activity produces phosgene gas (toxic) in the Hot Cell
4H-1	Cask lid dropped onto the stored waste in the Hot Cell.	11F-1	Loaded facility canister dropped in the Hot Cell.
5BD-1	Lifting fixture dropped onto the drums in the CUR.	12E-1	Drop the loaded facility canister into the Transfer Cell.
5CE-1	Drum carriage dropped while lifting due to carriage getting caught and over stressing fixture or basket in the CUR.	12E-2	Hot Cell Shield valve inadvertently closes on facility canister and shears the canister.
5CE-2	Drum carriage dropped inside the Hot Cell onto stored waste.	12E-3	Inadvertent movement of crane while lowering facility canister into Transfer Cell.
9-1	Fire in Hot Cell while containing stored waste.	12E-4	Inadvertent movement of the shuttle car with the facility canister partially lowered.
9-2	Fire/explosion in Hot Cell while containing stored waste.	14B-1	Robotic arm damages facility canister during contamination survey.
9-5	Shield plug lift fixture falls over in the Hot Cell.	20-1	Loss of confinement (LOC) in RH Bay due to seismic event (lid is loose on cask).
9AC-1	Empty facility canister dropped onto stored waste.	20-2	Full facility fire.
10A-1	Puncture drum in the Hot Cell with PAR manipulator.	20-3	LOC due to Tornado
10B-1	While lifting the drum, drum lid comes off in the Hot Cell.		

*Chemical/toxic exposure only

Table 5.1-9 Specific Accidents Selected for Quantitative Analysis

72-B Cask		
Grouped Event Description		**Individual Events Included (Study Node and Event**
1) Fire Underground	(RH1)	9-7, 10-2
2) Fire in the WHB	(RH2)	7-10
3) Loss of confinement (LOC) in the WHB	(RH3)	7-1, 7-2, 7-6
4) LOC Underground (waste hoist failure)	(RH4-A)	8-4, 8-6
5)LOC Underground (waste movement)	(RH4-B)	9-5, 10-1,10-5, 10-6
6) Fire followed by Explosion Underground	(RH5)	9-8, 10-3
7) Seismic Event	(RH6)	13-1
8) Tornado Event	(RH7)	13-2
9) Aircraft Crash	(RH8)	

10-160B Cask		
Grouped Event Description		**Individual Events Included (Study Node and Event**
1) Fire in Hot Cell	(NC1	9-1, 11D-1
2) Fire Underground	(NC2)	Same as RH1 (9-7, 10-2)
3) LOC in WHB	(NC3)	1B-6, 4D-1, 4F-1, 4G-1, 4H-1, 5BD-1, 5CE-1, 5CE-2, 9-5, 9AC-1, 10A-1, 10B-1, 10BF-1, 11D-3, 11F-1, 12E-1, 12E-2, 12E-3, 12E-4, 14B-1
4) LOC Transfer Cell & Underground	(NC4)	13ABCD-1 & 14ACDEFGHI-1 same as RH3; 15ABC-1 same as RH4-A; 16ABCD-1 & 17ABCD-1 same as RH4-B
5) Explosion followed by Fire in Hot Cell	(NC5)	9-2, 11D-2
6) Fire Followed by an Explosion Underground	(NC6)	Same as RH5 (9-8, 10-3)
7) Seismic Event	(NC7)	20-1, 20-2
8) Tornado Event	(NC8)	20-3

Table 5.1-10 HAZOP Accident Scenario Ranking

Accident	Scenario	# Node	Deviation	Consequence	Qualitative Consequence Ranking (Table 5.1-6)	Qualitative Frequency Ranking (Table 5.1-4)	Prevention/Mitigation
72-B Cask							
RH1	Fire in the Underground	9-7 Facility cask transfer to disposal room	Diesel fire on forklift	Potential for significant radioactive materials release	4	**4**	Prevention: Administrative Controls on fuel transfer and hot work permit. Mitigation: Vented canister, Fire suppression system (on forklift), Underground ventilation system, Mine worker training, Mine evacuation plan.
RH1	Fire in the Underground	10-2 Canister placement in borehole	Hydraulic fluid/diesel fuel fire	Potential for significant radioactive materials release	4	4	Prevention: Administrative Controls on fuel transfer and hot worker permit. Mitigation: Vented canister, Fire suppression system (on forklift and HERE), Underground ventilation system, Mine worker training, Mine evacuation plan.
RH2	Fire in the WHB	7-10 Load canister into facility cask	Hydraulic fluid fire	Potential for significant radioactive materials release	4	4	Prevention: Administrative Controls on fuel transfer and hot worker permit. Mitigation: Limited quantity (app. 40 gallons), Thermal detection alarms, Sprinkler system, Sump, Evacuation plan, Emergency exit.
RH3	LOC in the WHB	7-1 Load canister into facility cask	Excessive movement - Shuttle moves while crane is lifting canister	Potential for significant radioactive materials release	4	4	Prevention: Program for Shuttle and control equipment, Pre-op checks, PM program, Grapple hoist interlock. Mitigation: Limited access into Transfer Cell, Building Exhaust HEPA filtered, Emergency response plan and teams.

Table 5.1-10 HAZOP Accident Scenario Ranking **Page 2 of 13**

Accident	Scenario	# Node	Deviation	Consequence	Qualitative Consequence Ranking (Table 5.1-6)	Qualitative Frequency Ranking (Table 5.1-4)	Prevention/Mitigation
RH3	LOC in the WHB	7-2 Load canister into facility cask	Canister is dropped while being lifted into f canister falls back into 72B cask or onto Transfer Room floor	Potential for significant radioactive materials release	4	4	Prevention: Weight interlock on grapple, Type A container, PM program, Program for crane equipment and control equipment, Pre-op checks. Mitigation: Shielding, impact limiter on Transfer Cell floor, Limited access into Transfer Cell, Operator training & qualification, Building Exhaust HEPA Filtered, Emergency Response Plan and Teams.
RH3	LOC in the WHB	7-6 Load canister into facility cask	Shield valves (2) close on canister (sooner than desired)	Potential for significant radioactive materials release	4	4	Prevention: Control loop interlocks, Torque limiters on close of shield valves, PM program, Pre-op checks. Mitigation: Shielding, HEPA filtration, Differential pressure maintained by HVAC, Operator training & qualification, Emergency response plan and teams.
RH4-A	LOC in the U/G (waste hoist failure)	8-4 facility cask loaded onto conveyance	Incorrect conveyance position - Conveyance positioned at station, facility cask dropped onto conveyance	Potential for significant radioactive materials release	4	4	Prevention: Pivot rail stops, Car stops, Redundant verification of equipment readiness, Pivot rails interlocked to hoist position (hardwired). Mitigation: Physical barriers - shaft gates, Limited speed of facility cask transfer car, Cask Unloading Room doors, Shift to HEPA filtration, Operator training & qualification, Emergency response plan and teams.

Table 5.1-10 HAZOP Accident Scenario Ranking **Page 3 of 13**

Accident	Scenario	# Node	Deviation	Consequence	Qualitative Consequence Ranking (Table 5.1-6)	Qualitative Frequency Ranking (Table 5.1-4)	Prevention/Mitigation
RH4-A	LOC in the U/G (waste hoist failure)	8-6 facility cask loaded on conveyance	Loss of brakes on conveyance while loaded with facility cask - conveyance drops to bottom of waste shaft	Potential for significant radioactive materials release	4	4	Prevention: Brake system design (designated Safety Significant), Hoist equipment inspection program, PM program on hoist including brake system, Pre-op checks. Mitigation: Shift to HEPA filtration, Emergency response plan and teams.
RH4-B	LOC in the U/G	9-5 facility cask transfer to disposal room	Forklift drops facility cask	Potential for significant radioactive materials release	4	4	Prevention: Forklift inspection program, PM program facility cask design. Mitigation: Waste transit notification program, Shift to HEPA filtration, Operator training & qualification, Emergency response plan and teams.
RH4-B	LOC in the U/G	10-1 Canister emplaceme nt in borehole	Loss of control - forklift drops facility cask onto emplacement equipment	Potential for significant radioactive materials release	4	4	Prevention: facility cask design, equipment design, PM program, design of the drift, Traffic control program. Mitigation: Shift to HEPA filtration, Operator training & qualification, Emergency response plan and teams.

Table 5.1-10 HAZOP Accident Scenario Ranking

Accident	Scenario	# Node	Deviation	Consequence	Qualitative Consequence Ranking (Table 5.1-6)	Qualitative Frequency Ranking (Table 5.1-4)	Prevention/Mitigation
RH4-B	LOC in the U/G	10-5 Canister emplacement in borehole	Shield valve on emplacement equipment is closed on canister during emplacement process.	Potential for significant radioactive materials release	4	4	Prevention: Shield valve control interlocks, Torque limiter on shield valve motor, Control valve indicator signals shield valve problem, PM program, Pre-op checks. Mitigation: Radioactive material confined by emplacement equipment, Shift to HEPA filtration, Operator training & qualification, Emergency response plan and teams.
RH4-B	LOC in the U/G	10-6 Canister emplacement in borehole	Mis-alignment of canister as it is moved into borehole	Potential for radioactive materials release	3	4	Prevention: Stall pressure limit on ram, PM program, HERE is braced to opposing rib. Mitigation: Shift to HEPA filtration, Operator training & qualification, Emergency response plan and teams.
RH5	Fire followed by explosion U/G	9-8 facility cask transfer to disposal room	Diesel fire	Potential for significant radioactive materials release	4	4	Prevention: Administrative Controls on fuel transfer and hot work permit. Mitigation: Vented canister, Fire suppression system (on forklift), Underground ventilation system, Rescue program, Mine worker training, Mine evacuation plan.
RH5	Fire followed by explosion U/G	10-3 Canister emplacement in borehole	Hydraulic fluid/diesel fuel fire	Potential for significant radioactive materials release	4	4	Prevention: Administrative Controls on fuel transfer and hot work permit. Mitigation: Vented canister, Fire suppression system (on forklift and HERE), Underground ventilation system, Rescue program, Mine worker training, Mine evacuation plan.

Table 5.1-10 HAZOP Accident Scenario Ranking **Page 5 of 13**

Accident	Scenario	# Node	Deviation	Consequence	Qualitative Consequence Ranking (Table 5.1-6)	Qualitative Frequency Ranking (Table 5.1-4)	Prevention/Mitigation
RH6	Seismic	13-1 General Facility operation - NPH, External events	Seismic event (Design Basis Earthquake)	Potential for significant radioactive materials release	4	3	Prevention: WHB and equipment designed for DBE, 72B Cask design - meets DOT Type B shipping container certification requirements. Mitigation: HVAC system shutdown switch, Emergency response plan and teams; Recovery plan.
RH7	Tornado	13-2 General Facility operation - NPH, External events	Tornado event (Design Basis Tornado)	Potential for significant radioactive materials release	4	2	Prevention: WHB and equipment designed for DBT, 72B Cask design meets DOT Type B shipping container certification requirements. Mitigation: Weather monitored by CMR, Emergency response plan and teams; Recovery plan.

Table 5.1-10 HAZOP Accident Scenario Ranking **Page 6 of 13**

Accident	Scenario	# Node	Deviation	Consequence	Qualitative Consequence Ranking (Table 5.1-6)	Qualitative Frequency Ranking (Table 5.1-4)	Prevention/Mitigation
10-160-B Cask							
NC1	Fire in the Hot Cell	9-1 Move empty facility canister into Hot Cell and prepare facility canister	Fire in the Hot cell while containing stored waste	Potential for significant radioactive materials release	4	**4**	Prevention: PM Program on electrical equipment; Remote location of electrical circuits protective devices; Hot Cell design; Limited ignition sources. Mitigation: Fire loading/Combustible Control Program; Procedures and Training.
NC1	Fire in the Hot Cell	11D-1 Prepare facility canister for disposal	Fire in the Hot Cell	Potential for significant radioactive materials release	4	4	Prevention: Storage limits on waste (i.e., LFL); Lid design; Canister design. Mitigation: Fire loading/Combustible Control Program; Procedures and Training; Thermal detector; Shield door closed in the CUR; Shield plug in Hot Cell is in place.
NC3-A	LOC in the WHB	4F-1 Remove cask lid from cask in CUR	Shield plug dropped onto stored facility canister in Hot Cell	Potential for significant radioactive materials release	4	4	Prevention: PM Program on crane; Crane design; Facility design. Mitigation: Procedures and Training; Ventilation system; CAMs; Emergency response procedure; Shield door crane interlock.
NC3-A	LOC in the WHB	4H-1 Remove cask lid from cask in CUR	Cask lid dropped onto stored waste in Hot Cell	Potential for significant radioactive materials release	4	4	Prevention: PM Program on crane; Crane design; Facility design. Mitigation: Procedures and Training; Ventilation system; CAMs; Emergency response procedure; Shield door crane interlock.

Table 5.1-10 HAZOP Accident Scenario Ranking

Accident	Scenario	# Node	Deviation	Consequence	Qualitative Consequence Ranking (Table 5.1-6)	Qualitative Frequency Ranking (Table 5.1-4)	Prevention/Mitigation
NC3-A	LOC in the WHB	5CE-2 Unload the cask in the CUR	Drum carriage dropped inside the Hot Cell onto stored waste	Potential for significant radioactive materials release	4	4	Prevention: PM Program on crane; Crane design; Fixture design; Drum carriage design. Mitigation: Procedures and Training; Ventilation system; Emergency response procedure.
NC3-A	LOC in the WHB	9-5 Move empty facility canister into Hot Cell and Prepare facility canister	Shield plug lift fixture falls over in the Hot Cell	Potential for significant radioactive materials release	4	4	Prevention: Hot Cell leaded glass (outer layer). Mitigation: Procedures and Training; Ventilation system.
NC3-A	LOC in the WHB	9AC-1 Move empty facility canister into Hot Cell and Prepare facility canister	Empty facility canister dropped onto stored waste in Hot Cell	Potential for significant radioactive materials release	4	4	Prevention: PM Program on crane; Crane/grapple design; Facility design. Mitigation: Procedures and Training; Ventilation system; CAMs; Emergency response procedure; Weight of Empty canister; Shield door crane interlock; Shield plug in Hot Cell is in place.
NC3-B	LOC in the WHB	4G-1 Remove cask lid from cask in CUR	Cask lid dropped onto the cask and drums in CUR	Potential for significant radioactive materials release	4	4	Prevention: PM Program on crane; Crane design; Facility design. Mitigation: Procedures and Training; Ventilation system; CAMs; Emergency response procedure; Shield door crane interlock.

Table 5.1-10 HAZOP Accident Scenario Ranking

Accident	Scenario	# Node	Deviation	Consequence	Qualitative Consequence Ranking (Table 5.1-6)	Qualitative Frequency Ranking (Table 5.1-4)	Prevention/Mitigation
NC3-B	LOC in the WHB	5BD-1 Unload the cask in the CUR	Lifting fixture dropped onto the drums in CUR	Potential for significant radioactive materials release	4	4	Prevention: PM Program on crane; Crane design; Fixture design; Facility design. Mitigation: Procedures and Training; Ventilation system; CAMs; Emergency response procedure; Shield door crane interlock.
NC3-C	LOC in the WHB	10B-1 Unload carriage units in Hot Cell	While lifting a drum, drum lid comes off in the Hot Cell	Potential for significant radioactive materials release	4	4	Prevention: Drum design; Drum inspection. Mitigation: Procedures and Training; Ventilation system; WAC; Shield plug in Hot Cell is in place; Shield door crane interlock.
NC3-C	LOC in the WHB	10BF-1 Unload carriage units in Hot Cell	While lifting a drum, drop drum in the Hot Cell.	Potential for significant radioactive materials release	4	4	Prevention: PM Program on crane; Crane design; Facility design. Mitigation: Procedures and Training; Ventilation system; CAMs; Shield plug in Hot Cell is in place; Shield door crane interlock; Emergency response procedure.
NC3-C	LOC in the WHB	11F-1 Prepare facility canister for disposal	Loaded facility canister dropped in the Hot Cell	Potential for radioactive materials release	4	4	Prevention: PM Program on crane; Grapple design; Facility design. Mitigation: Procedures and Training; Ventilation system; CAMs; Canister design; Drum design; Shield plug in Hot Cell is in place; Shield door crane interlock; Emergency response procedure.

Table 5.1-10 HAZOP Accident Scenario Ranking **Page 9 of 13**

Accident	Scenario	# Node	Deviation	Consequence	Qualitative Consequence Ranking (Table 5.1-6)	Qualitative Frequency Ranking (Table 5.1-4)	Prevention/Mitigation
NC3-D	LOC Confinement in the WHB	5CE-1 Unload the cask in the CUR	Drum carriage dropped while lifting due to carriage getting caught and over stressing fixture or basket in the CUR	Potential for significant radioactive materials release	4	4	<u>Prevention:</u> PM Program on crane; Fixture design; Drum carriage design; Crane design. <u>Mitigation:</u> Procedures and Training; Ventilation system; Shield door crane interlock; Emergency response procedure.
NC3-D	LOC in the WHB	12E-1 facility canister transfer to shuttle car in Transfer Cell	Drop the loaded facility canister into the Transfer Cell	Potential for significant radioactive materials release	4	4	<u>Prevention:</u> PM Program on crane; Guide tubes; Shuttle car design; Impact limiter on floor. <u>Mitigation:</u> Procedures and Training; Ventilation system; Emergency response procedure.
NC3-E	LOC in the WHB	10A-1 Unload carriage units in Hot Cell	Puncture drum in the Hot Cell with PAR manipulator	Potential for significant radioactive materials release	4	4	<u>Prevention:</u> PM Program on PAR manipulator; Crane design; Facility design. <u>Mitigation:</u> Procedures and Training; Ventilation system; CAMs; Emergency response procedure; Shield plug in Hot Cell is in place; Shield door crane interlock.

Table 5.1-10 HAZOP Accident Scenario Ranking **Page 10 of 13**

Accident	Scenario	# Node	Deviation	Consequence	Qualitative Consequence Ranking (Table 5.1-6)	Qualitative Frequency Ranking (Table 5.1-4)	Prevention/Mitigation
NC3-F	LOC in the WHB	12E-2 facility canister transfer to shuttle car in Transfer Cell	Hot Cell shield valve inadvertently closes on facility canister and shears the canister	Potential for significant radioactive materials release	4	4	Prevention: PM Program on shield valve; Crane and Hot Cell shield valve interlock; Torque limiter on shield valve; Canister design. Mitigation: Procedures and Training; Ventilation system; Emergency response procedure.
NC3-F	LOC in the WHB	12E-3 facility canister transfer to shuttle car in Transfer Cell	Inadvertent movement of crane while lowering facility canister partially lowered	Potential for significant radioactive materials release	4	4	Prevention: PM Program on crane; Crane and Hot Cell shield valve interlock; Torque limiter on shield valve; Canister design. Mitigation: Procedures and Training; Ventilation system; Emergency response procedure.
NC3-F	LOC in the WHB	12E-4 facility canister transfer to shuttle car in Transfer Cell	Inadvertent movement of shuttle car with facility canister into Transfer Cell	Potential for significant radioactive materials release	4	4	Prevention: PM Program on shield valve/shuttle car interlock; Variable speed drive motor controller; Interlock between shuttle car and shield valve; Drive train on shuttle car - belts will slip; Canister design. Mitigation: Procedures and Training; Ventilation system; Emergency response procedure.

Table 5.1-10 HAZOP Accident Scenario Ranking **Page 11 of 13**

Accident	Scenario	# Node	Deviation	Consequence	Qualitative Consequence Ranking (Table 5.1-6)	Qualitative Frequency Ranking (Table 5.1-4)	Prevention/Mitigation
NC3-F	LOC in the WHB	14B-1 Load facility canister into facility cask from the Transfer Cell	Robotic arm damages facility canister during contamination survey	Potential for significant radioactive materials release	4	4	Prevention: Robot design; Collision detector; Force limiter on swipe arm. Mitigation: Procedures and Training; Ventilation system; Emergency response procedure.
NC3-G	LOC in the WHB	1B-6 Cask receipt and transfer in RH Bay	While moving compressed gas cylinder in RH Bay, cylinder falls, ruptures, and impacts cask	Potential for significant radioactive materials release	4	4	Prevention: Special cart; Cylinder design; Limited number and movement of cylinders. Mitigation: Procedures and Training; Ventilation system; Emergency response procedure.
NC3-H	LOC in the WHB	4D-1 Remove cask lid from cask in CUR	Cask falls off of RCTC in RH Bay while lid is loose	Potential for significant radioactive materials release	4	4	Prevention: Transfer car design; Limited speed of transfer car . Mitigation: Procedures and Training; Cask; DOT Type A drums; ARMs and CAMs; Ventilation system; Emergency response procedure; Nuclear coating on floor.
NC4	LOC in the Transfer Cell or Underground	13ABCD-1 Move facility canister into position in the Transfer Cell	Same as RH3				

Table 5.1-10 HAZOP Accident Scenario Ranking **Page 12 of 13**

Accident	Scenario	# Node	Deviation	Consequence	Qualitative Consequence Ranking (Table 5.1-6)	Qualitative Frequency Ranking (Table 5.1-4)	Prevention/Mitigation
NC4	LOC in the Transfer Cell or Underground	14ACDEFGHI-1 Load facility canister into facility cask from Transfer Cell	Same as RH4A				
NC4	LOC in the Transfer Cell or Underground	15ABC-1 facility cask onto hoist	Same as RH4A				
NC-4	LOC in the Transfer Cell or Underground	16ABCD-1 facility cask transfer to disposal room	Same as events RH4B				
NC-4	LOC in the Transfer Cell or Underground	17ABCD-1 Cask emplacement in bore hole	Same as RH5				
NC5	Explosion followed by fire in the Hot Cell	9-2 Move empty facility canister into Hot Cell and Prepare facility canister	Fire/explosion in Hot Cell while containing stored waste	Potential for significant radioactive materials release	4	4	<u>Prevention:</u> WAC - no flammable items in the drum, limits on gas generation; Limited storage. <u>Mitigation:</u> Procedures and Training; Ventilation system; Emergency response procedure; Shield plug in Hot Cell is in place; Shield door closed.

Table 5.1-10 HAZOP Accident Scenario Ranking **Page 13 of 13**

Accident	Scenario	# Node	Deviation	Consequence	Qualitative Consequence Ranking (Table 5.1-6)	Qualitative Frequency Ranking (Table 5.1-4)	Prevention/Mitigation
NC-5	Explosion followed by fire in the Hot Cell	11D-2 Prepare facility canister for disposal	Explosion in the Hot Cell	Potential for significant radioactive materials release	4	4	Prevention: Welder removed; WAC - no flammable items in the drum, limits on gas generation; Vented drums and canister; Canister lid design; Limited storage. Mitigation: Procedures and Training; Ventilation system; CAMs; Emergency response procedure; Shield plug in Hot Cell is in place; Shield door crane interlock.
NC-7	Seismic event	20-1 Natural events	Seismic event (Design Basis Earthquake)	Potential for significant radioactive materials release	4	3	Prevention: WHB (and certain equipment) designed for DBE; Crane, PAR, and Hot Cell and equipment in it is DBE qualified. Mitigation: HVAC system shutdown switch, Emergency response plan and teams; Recovery plan.
NC-7	Seismic event	20-2 Natural events	Full facility fire	Potential for significant radioactive materials release	4	3	Prevention: Limited ignition sources. Mitigation: HVAC system shutdown switch; Fire loading/Combustible Control Program; Emergency response plan and teams; Recovery plan.
NC8	Tornado	20-3 Natural events	Tornado event (Design Basis Tornado)	Potential for significant radioactive materials release	4	2	Prevention: WHB (and certain equipment) designed for DBT; Weather monitored by CMR; 10-160B cask is DBT qualified Mitigation: Emergency response plan and teams; Recovery plan.

Table 5.1-11 Summary of Potential Controls for Immediate Worker Protection Page 1 of 3

Study Node/ Event (defined in HAZOP)	**Radiological Rank (Cons., Freq.) (defined in HAZOP)**	**Preventive Feature**	**Mitigative Features**	**Mitigated Consequences**
72-B Cask				
1-4	2,4		Rad Con procedures; Operator training; ALARA Program; Dosimetry; 72B cask design (contact dose rate ≤ 200 mrem/hr)	Below Guideline (≤ 5 rem)
6-1	2,4	Cask and canister design	Shuttle and shuttle support design; Operator training; Limited access into Transfer Cell; 72Bcask design (contact dose rate ≤ 200 mrem/hr)	None
7-4	2,4	Fail safe design of floor port shield; Control Loop Interlock; Pre-operational checks; Preventive maintenance	Shielding for operator at control panel	None
7-5	2,4	PLC interlock with facility cask top shield valve; Pre-operational checks; Preventive maintenance	Shielding for operator at control panel	None
14-1	2,4		Shift to HEPA filtration; Room Closure System; Canister	Below Guideline (≤ 5 rem)

Table 5.1-11 Summary of Potential Controls for Immediate Worker Protection Page 2 of 3

Study Node/ Event (defined in HAZOP)	**Radiological Rank (Cons., Freq.) (defined in HAZOP)**	**Preventive Feature**	**Mitigative Features**	**Mitigated Consequences**
10-160B Cask				
1A-4	2,4		Rad Con procedures; Operator training; ALARA Program; Dosimetry; Cask design (contact dose rate ≤ 200 mrem/hr); Inspection and survey in transit	Below Guideline (≤ 5 rem)
5CE-3	2,4	Preventive maintenance on crane and windows (N_2 bladders in windows have pressure relief valves); Hot cell leaded glass on outer layer	Training and Procedures	None
9-8	2,4		Training and Procedures; Personal Protective Equipment; Bag out process for HEPA filter change-out	Below Guideline (≤ 5 rem)
9-9	3,4	Administrative controls for lock and key; ARM indicators in the Hot Cell and Transfer Cell	Training and Procedures	None
10C-1	2,4	Glove box design; inspection of gloves; Preventive maintenance on Glove box	Training and Procedures	
10D-1	2,4	Interlocks prevent opening both doors (on Glove box drawer) at the same time; Glove box design; Glove box not in normal streaming path	Training and Procedures	None

Table 5.1-11 Summary of Potential Controls for Immediate Worker Protection **Page 3 of 3**

Study Node/ Event (defined in HAZOP)	**Radiological Rank (Cons., Freq.) (defined in HAZOP)**	**Preventive Feature**	**Mitigative Features**	**Mitigated Consequences**
10-160B Cask				
21-5	2,4	Program on facility heating; Redundant ventilation trains (design); 10-stage sequence heater; Emergency management loss of power; drums on floor stacked 1-high are below streaming path		None

5.2 RH TRU Accident Analysis

This section quantitatively analyzes the postulated accident scenarios selected as discussed in Section 5.1.4. The selected accidents are considered "Derivative Design Basis Accidents," (DBAs) as defined in DOE Standard 3009-94.[1] These derivative DBAs are used to estimate the response of WIPP systems, structures, and components (SSCs) to "the range of accident scenarios" that bound "the envelope of accident conditions to which the facility could be subjected" in order to evaluate accident consequences. The principal purpose of the accident analysis is to evaluate the derivative DBAs for the purposes of identifying safety (safety-class or safety-significant) SSCs and Technical Safety Requirements (TSRs) necessary to maintain accident consequences resulting from these derivative DBAs to within the accident risk evaluation guidelines. For the purposes of establishing safety SSCs, the consequences of these accidents are analyzed to a non-involved worker conservatively assumed to be 328 ft (100 m.) from each release point, and to the maximally exposed individual (MEI) located at the WIPP Exclusive Use Area boundary. An evaluation of operational "beyond" derivative DBAs (BDBA) design basis is conducted by evaluating the accident scenarios in response to the bounding conditions as derived from the TSRs, Attachment 1 to the SAR. For simplicity, the term "derivative" is dropped for the remainder of this chapter; DBA refers to derivative DBAs.

DOE Standard 3009-94[1] states that use of a lower binning threshold such as 1E-06/yr is generally appropriate, but should not be used as an absolute cutoff for dismissing physically credible low frequency operational accidents without an evaluation of preventative or mitigative features. DBAs identified in this section whose frequency are less than 1E-06/yr (beyond extremely unlikely), are also analyzed quantitatively for the sole purpose of providing a perspective of the risk associated with the operation of the facility. The results of these analysis are found in the respective accident evaluation in Section 5.2.4.

The immediate worker is that individual directly involved with the waste handling operation for which the accident is postulated. As discussed in Sections 5.1.2.1.2 and 5.1.7, the assessment of immediate worker consequences will ensure that the maximum allowable radionuclide inventory, in conjunction with the other layers of defense-in-depth, will preclude worker exposure from being unacceptable.

The models and assumptions used in the analysis for determining the amount of radioactivity released to the environment and the extent of exposure to the MEI, non-involved worker, and immediate worker are provided in the following sections. Activity releases to the environment are given for each postulated accident. Committed Effective Dose Equivalents (50 yr CEDE) were calculated for what are considered to be hypothetical individuals located: (1) MEI at the WIPP Exclusive Use Area boundary and off-site public at the site boundary (16 section boundary), (2) non-involved worker at 328 ft (100 m) from each release point, and (3) immediate worker within the immediate area of the accident. The meteorological conditions under which these doses are evaluated are discussed in Section 5.2.1.

The radioactive material in the RH waste that has the potential to be released to the off-site environment (except contamination on the 72-B canister or on the surfaces of the drums in the 10-160B cask) is contained within the 72-B waste canisters or 10-160B drums. The physical properties and assumptions for RH waste canister and drum inventories used in this analysis are presented in Section 5.1.2.

In evaluating hypothetical accidents, the level of conservatism in the safety analysis assumptions provide consequences which result in postulated releases that are overestimated rather than underestimated. The level of conservatism in each of the safety analysis variables is consistent with DOE-STD-3009-94[1]. The level of conservatism chosen provides reasonable assurance that when considering the variability in waste form, TRU activity content, and radionuclide distributions : (1) the safety envelope of the facility is defined, (2) the design of the facility is adequate in response to the accident scenarios analyzed, and (3) the TSRs derived will provide for the protection of the public, the worker, and the environment.

Based on the results of both RH HAZOPs, operational events are binned into three major accident categories, fire, explosion, and waste container breaches. Since breaches of waste containers may occur due to drop or vehicle impact, accidents involving both of these breach mechanisms are evaluated. Accidents involving waste container drops are evaluated based on the energy involved due to drop height. Due to the differences in release and dispersion mechanisms possible, accidents of each category are evaluated for the surface and Underground areas of the facility. Operational, natural phenomena and external initiating events that require evaluation as determined by the hazard analysis are listed below. Note that the events are designated as NC for the 10-160B cask and RH for the 72B cask.

1. Operational Events

   Fires

   - RH1 Fire in the Underground
   - RH2 Fire in the WHB
   - NC1 Fire in the Hot Cell
   - NC2 Fire in the Underground

   Waste Canister Breaches

   - RH3 Loss of Confinement (LOC) in the WHB
   - RH4-A LOC in the Underground (Waste Hoist Failure)
   - RH4-B LOC in the Underground
   - NC4 LOC in the Transfer Cell or Underground

   Waste Drum Breaches

   - NC3 LOC in the WHB

   Explosion

   - RH5 Fire Followed by Explosion in the Underground
   - NC5 Explosion Followed by Fire in the Hot Cell
   - NC6 Fire Followed by Explosion in the Underground

2. Natural Phenomena Events

   - RH6 & NC7 Seismic Events
   - RH7 & NC8 Tornado Events

3 External Events

- Aircraft Crash (applicable to both 72B and 10-160B operations)

5.2.1 Accident Assessment Methodology

5.2.1.1 Non-involved Worker and MEI Accident Assessment Methodology

Receptors

A hypothetical MEI located at the Exclusive Use area boundary (Figure 5.2-1) was selected for the accident-related consequence assessment. Review of the WIPP Land Management Plan[2] indicates that public access to the WIPP 16-section area up to the exclusive use area shown in Figure 5.2-1 is allowed for grazing purposes, and up to the DOE off limits area "for recreational purposes." Although analysis is traditionally conducted for an MEI at the facility site boundary, the assumed location of the MEI for this analysis is at the "closest point of public access," or at the boundary of the DOE "exclusive use area." The location of the MEI is also consistent with Appendix D9 of DOE/WIPP-91-005, Waste Isolation Pilot Plant RCRA Part B Permit Application, Revision 6, U.S. Department of Energy, Carlsbad, N.M. [3] Calculations are also performed using the site boundary for reference purposes.

Although the prevailing winds at WIPP are towards the northwest, the closest distance to the exclusive use area (without regard to direction) from the exhaust shaft vent and the WHB vent was used in the dose assessment calculations. The closest distance to the exclusive use area boundary from the exhaust shaft vent is approximately 935 ft (285 m) and the closest distance to the exclusive use area boundary from the WHB lies southeast at approximately 1150 ft (350 m) (Figure 5.2-2).

The non-involved worker is assumed to be a worker not directly involved with the waste handling operation for which the accident is postulated and located at a distance of 328 ft (100 m) from each release point due to the restrictions on dispersion modeling at close in distances.

Source Term Methodology

The following equation from DOE Handbook 3010-94, Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities,[4] reflects the calculation for source term:

Q = MAR * DR * ARF * RF * LPF

where:

Q The Source Term (Ci or mg) - Total curies released.

MAR Material At Risk, the maximum amount and type of material present that may be acted upon with the potentially dispersive energy source (Ci or mg).

DR Damage Ratio, the fraction of the MAR actually impacted by the accident condition.

ARF Airborne Release Fraction, the fraction of that radioactive material actually impacted by the accident condition that is suspended in air.

RF Respirable Fraction, the fraction of the airborne radioactive particles that are in the respirable size range, i.e. less than 10 μm in aerodynamic equivalent diameter.

LPF Leakpath Factor, the cumulative fraction of airborne material that escapes to the atmosphere from the postulated accident.

The quantity MAR is calculated as the quantity (CI * CD), where CI is the waste canister or waste drum radiological or non-radiological inventory, CD is the number of canisters or waste drums damaged by the accident phenomenon (number of canisters or drums breached).

The resulting equation is:

Q = CI * CD * DR * ARF * RF * LPF (5-1)

Each of the source term variables are a function of the accident phenomenon under consideration and are derived in the following discussions. The level of conservatism in each of the safety analysis variables is consistent with DOE-STD-3009-94[1] and its Appendix A.

Waste Container Radiological and Non-radiological Inventories (CI) and Containers Damaged (CD)

The source term equation radiological CI used in the accident analyses, is based on the waste characterization analyses in Section 5.1.2. As described in Section 5.1.2.1, the maximum 72-B canister radionuclide inventory that is not solidified, vitrified, or overpacked is 80 PE-Ci for direct loaded waste and 240 PE-Ci for double contained or overpacked waste. Since one 72-B waste canister is processed at a time, CD = 1 for all 72-B accident scenarios. The maximum 10-160B cask radionuclide inventory is 20 PE-Ci. The 10-160B cask can contain up to ten waste drums. As a conservative assumption, it is assumed that all of the radionuclide inventory from a single 10-160B cask is located in a single waste drum from that cask. Additionally, the RCRA permit application for WIPP allows the storage of up to six fully loaded facility canisters (each containing three waste drums) with possibly one of them partially loaded (1 or 2 drums) in the Hot Cell during processing of 10-160B casks. It is possible that the radionuclide inventory from two 10-160B casks (40 PE-Ci) may be at risk in accident scenarios that occur in the Hot Cell. It is also possible, but extremely unlikely that the three drums in a facility canister each contains the maximum radiological contents of a 10-160B cask. Therefore, the bounding activity in a single facility canister is considered to be 60 PE-Ci. For the accident analysis, the CI is set to 20 PE-Ci and the CD is determined on a scenario-specific basis (CD = 1 or 2 for drum events or CD= 3 for facility canister events) based on whether or not more than one waste drum may be at risk in the specific accident scenario being analyzed.

The three types of accident scenarios identified for quantitative analysis: (1) potential fires that can compromise the containment integrity of the waste drums and/or canisters, (2) potential explosion that can cause a breach of the waste drums and/or canisters, and (3) waste drum and/or canister breaches from drops or waste handling equipment impacts. The waste forms defined in the Baseline Inventory Report[5] (BIR) were examined to determine the types most susceptible to these scenarios. For waste drum and/or canister fire scenarios, combustible waste is defined as consisting of paper, kimwipes, and cloth (dry and damp); various plastics such as polyethylene and polyvinyl chloride; wood; and filters contaminated with trace quantities of halogenated organic solvents; and non-combustibles as sludges, filters, asphalt, soil, glass, metal, and others.

Therefore, it is conservatively assumed that during potential fire, a waste drum and/or canister could contain waste with a 95 percent combustible and 5 percent non-combustible content. Since the fire is assumed to impact a single 72-B waste canister (CD=1), the CI for the fire scenarios is 80 PE-Ci for direct loaded waste and 240 PE-Ci for double confined waste. For the 10-160B fire scenarios, NC1 and NC2, the CDs are determined in the accident analyses.

For waste drum and/or canister breach scenarios resulting from drops or impacts, the accident is characterized by a sharp impact to the waste drum and/or canister and damage to the waste canister, followed by an airborne release of radioactivity due to shock/vibration effects. The waste forms defined in the BIR[5] were examined to determine the types most susceptible to waste canister breach scenarios. Based on DOE-HDBK-3010-94,[4] non-combustible waste forms that have a hard, unyielding surface and do not undergo brittle fracture are the most susceptible to the airborne release of radioactivity in highly respirable form due to shock/vibration effects. Although DOE-HDBK-3010-94[4] bounding airborne release fraction for combustible and non-combustible waste is the same (1E-03), the respirable fraction is higher for noncombustibles (1.0) than for combustibles (0.1). Therefore, it is conservatively assumed that the breach accident scenarios occur with waste drums and/or canisters classified as containing non-combustible uncategorized metal waste, with a 95 percent non-combustible and 5 percent combustible content. As discussed earlier, at most two waste drums containing the entire radionuclide inventory from two 10-160B casks may be at risk of damage from a breach accident. Therefore, the number of drums impacted (CD = 1 or CD = 2) is determined by the specifics of the accident scenario.

Uncategorized metal waste is chosen for drop and impact scenarios due to: (1) the relatively high waste volume fraction (approximately 9 percent) of the total stored waste volume, and (2) the combustible and non-combustible fractions from the definition of the waste form in the BIR[5]. Although heterogeneous waste has the highest stored volume fraction (approximately 59 percent), based on the definitions in the BIR, uncategorized metal waste has the highest projected volume fraction (approximately 77 percent) and highest potential fraction of non-combustible waste fraction (95 percent), and is therefore more conservative for use in accident analysis calculations.

Based on the data in Table A-1 of Appendix A, use of the above values for CI and combustible/non-combustible fractions provides reasonable assurance of obtaining bounding consequences in the potential fire, explosion, and waste drum and/or canister breach accident consequence analysis.

The non-radiological CI development process for events which involve a breach of a waste canister or drum is simplified by assuming that 100 percent of the VOC headspace inventory is released instantaneously. VOCs selected for consideration for accidental releases are listed in Table 5.1-2. The values were scaled for estimating concentrations in the waste drum or canister based on the volume of the container.

Solid and liquid chemical concentrations that would be expected to be within a waste drum or canister is the same as for CH waste and are listed in Table 5.1-3. These values were scaled for estimating concentrations in the waste canister based on bounding weight of material in a waste canister. Radiological and chemical source terms developed for specific accidents are estimated using Equation 5-1.

For the radiological CI, the CD is limited to either 1 or 2 as discussed previously. However, for the non-radiological inventory, all of the waste drums are assumed to contain equal inventories. Therefore, as many as 20 waste drums could be at risk for damage and release of non-radiological hazardous material. The CD is determined for each of the accident scenarios on the basis of the specifics for the scenario. Note that this means that the CD for the radiological and non-radiological releases may be different for the same accident scenario.

Damage Ratio (DR)

Based on the discussion in Section A.3.2 of DOE-STD-3009-94,[1] material actually impacted by the accident generated conditions are acceptable for estimation of the DR. There are no releases from fires involving the 72B cask and/or canister. Since the fires included in the accident analysis for 10-160B cask processing are external to the waste drums, the amount of the combustible material that is actually burned is limited by the amount of oxidant (air) that is present in the drum to support combustion. The analysis performed for the CH TRU Central Characterization facility showed that only 16.3 percent of the combustible material in the waste drums is actually burned. As a result of the airborne release generated by the fire phenomenon, it is assumed that the conservative radiological DR for the 10-160B fire events is 1.0 (DR=1.0) while the non-radiological DR = 0.163.

For waste canister or drum breaches from drops, two specific accident conditions are examined: (1) drops from heights less than 4 ft (1.2m) ($h \leq 4$ ft [1.2m]) and (2) drops from heights equal to or less than 22 ft (6.7 m), [4 ft (1.2 m) < $h \leq 22$ ft (6.7 m)]. It is assumed that a waste canister inside the facility cask will maintain its structural integrity and its containment function if the facility cask is impacted by a forklift or if it is involved in a collision with another vehicle while being transported by a forklift.

For waste canister or drum breaches from drops, the DR is based on the extensive analysis performed for the CH waste drums. That analysis showed that for DOT Type A drums weighing 1000 pounds or less a conservative DR of 0.025 for drops of greater than 5 feet but less than or equal to 10 feet is applicable. This drop height is typical of drops from the cranes and manipulators involved in handling the waste drums from a 10-160B cask. The DR for waste drum breach accidents involving dropping a waste drum is 0.025 (DR = 0.025).

Another type of accident involving breach of a waste drum involves dropping a heavy object, such as the Hot Cell shield plug, on a waste drum. The DR is a function of the kinetic energy which is in turn a function of the weight of the dropped object. In this case, the drum is not dropped but is impacted by a dropped object. The result on the drum is the same. Since the weight of the object dropped on the drum could be more than the 1000 lbs used for the basis for the DR for dropping a waste drum, it is assumed that the DR for this case is larger than the 0.025 value for a drum drop of between 5 and 10 feet. The shield plug weight is approximately 4 times the 1000 pound weight of a waste drum, it is assumed that the impact of the shield plug on a waste drum would result in a DR four times the DR for dropping a 1000 pound waste drum the same height. It is conservatively assumed that the DR is (4 x 0.025 =) 0.1 for this event.

The other two types of accidents involving the breach of a waste drum are puncture scenarios. In one scenario, an unprotected waste drum is punctured during waste handling operations. From section 5.2.1.1 of the WIPP CH SAR[6], the DR for DOT Type A waste drum breached by impact with waste handling equipment is 0.05 (DR = 0.05). The other puncture accident involves puncturing a waste drum while contained in the 10-160B cask. Since this would require penetrating two barriers, the DR would be smaller than the DR for puncturing an unprotected waste drum. The DR for double confined waste is a factor of 10 lower than single confined waste. Based on the ruggedness of the 10-160B cask, it is conservatively assumed that the DR is a factor of 2 smaller than the DR for puncture of an unprotected waste drum. The DR for puncturing a waste drum inside a 10-160B cask is 0.025 (DR = 0.025).

For the explosion accident scenarios, there are two potential accident stresses acting on the MAR. One is the shock and blast effects of the initial explosion and the second is the thermal impact of the follow-on fire. These different stressors have different mechanisms of impacting the waste material and, therefore, have potentially different damage ratios.

The DR for the explosion accident stress is determined by the physical arrangement of the waste in the drum. The flammable gas that is generated in a waste drum collects in the headspace of the drum causing the explosive stress to act on the top portion of the waste. The waste in the lower part of the drum will be shielded from the direct shock and blast effects by the waste in the top part. The primary effect of the explosion on the material is equivalent to the phenomena of accelerated airflow parallel to the surface. This characterization of the stress indicates that only the top few inches of the waste in the drum will be subject to the stress but a conservative DR of 1.0 is used for the explosive stress.

The DR for the thermal effects of a fire on the waste drum can be limited by the lack of free air flow into the drum. However, in this case, the initial explosion will result in at least a partial structural failure of the drum which would allow more air flow to feed the follow-on fire. Based on this, the DR for the follow-on fire is conservatively assumed to be 1.0.

The explosive stress could cause shrapnel to impact waste drums stored near the drum in which the explosion occurs which could result in puncturing of nearby waste drums. Since the DR for puncture of a waste drum by waste handling equipment is 0.05, it is assumed that the same DR applies to a waste drum punctured by shrapnel generated by an explosion.

The upper limit for a drop in which waste canisters are certified (DOT Type A) to not release any of their solid waste form contents is 4 ft (1.2 m). The DR for drops of waste canisters from less than or equal to 4 ft (1.2 m) is zero (DR=0). Tests performed on Type A packaging[8,9,10,11] and their simulated contents provides useful data to estimate damage to the RH waste canisters from drops greater than 4 ft and assign an estimated DR. Since the conditions associated with the accident scenarios analyzed for the RH waste handling operations (such as waste canisters dropped by a grapple hoist or facility cask dropped by a forklift), differ from those in the relatively small amount of well-documented tests, the estimates of the amount of material released for RH waste containers for the postulated accident conditions are based primarily on the structural assessment provided in PLG-1305, Remote Handled Transuranic Waste Container (RH TWC) Structural Analyses for Postulated Handling Accidents.[12]

This analysis looked at several scenarios for damaging the 72B canister which included drops of greater than 4 ft and damage resulting from motive force provided by the system and involve the slow crushing of the container.

The bounding drop scenario involved a slightly inclined drop of a direct loaded 72B canister, resulting in an edge hit on the inside rim of the road cask opening. The canister suffers sufficient damage to allow 100 percent of the contained waste to fall into the 72B cask. The bounding DR for directly loaded 72B canister after an inclined drop is 1.0 (DR=1.0).

The 72B canister can hold three 55-gallon drums of RH waste. For conservatism, it is assumed that all of the waste is in the bottom drum, and that drum is impacted by the accident conditions and releases 10 percent of its contents. Assuming a conservative DR for drum of 0.1 and 1.0 for the 72B canister, a conservative DR for an inclined drop of a 72B canister containing 3 55-gal drums would be 0.1 x 1 = 0.1 (DR=0.1).

The crushing scenarios were modeled to produce rupture, or almost rupture in order to determine the force required to produce a release. A force of 11,000 lbs on the shuttle car with a canister partially in the road cask/shielded insert would be required to produce a bending that does not cause rupture in the canister. This is much more than the force of approximately 2000 lbs required to move the shuttle car between transfer positions. A second crushing scenario involved accidental closing of a shield valve on a canister. Calculations show that 39 kips (almost 20 tons) of force must be exerted by a shield valve closure in order to initiate a canister rupture. The force required to simply open and close the shield valve is approximately 500 lbs. Passive and active engineered design features which prevent these scenarios from occurring are described in section 5.2.3.3.

For the waste hoist accident scenario which involves a facility cask, containing a waste canister, drop of over 2,000 ft (609.6 m), it is conservatively assumed that breach of the facility cask and waste canister occurs resulting in a bounding DR of 0.25 for direct loaded waste and 0.025 for double confined waste.

Airborne Release (ARF) and Respirable (RF) Fractions

Based on the discussion in Section A.3.2 of Appendix A of DOE-STD-3009-94,[1] bounding values for the ARFs and the RFs are utilized based on DOE-HDBK-3010-94.[4] The ARF for the burning of contaminated combustible materials in a waste canister is 5.0E-04 and the ARF for non-combustible materials in a canister is 6.0E-03. These values represent bounding ARFs for the burning of contaminated packaged mixed waste and the heating of non-combustible contaminated surfaces (DOE-HDBK-3010-94, subsections 5.2.1.1 and 5.3.1).[4] The bounding RFs for the burning of contaminated packaged mixed waste and the heating of non-combustible contaminated surfaces are 1.0 and 1.0E-02, respectively (DOE-HDBK-3010-94, subsection 5.2.1.1 and 5.3.1).[4]. The bounding value for ARF for burning of contaminated packaged mixed waste is a conservative value. Some of the conservative factors involved in the determination of the ARF as they apply to this analysis include:

- The experiments on which the determination of ARF are based were designed to represent loosely packed waste in cardboard boxes. The waste drums that will be temporarily stored in the Hot Cell are much more substantial (DOT Type A containers). Therefore, the experiments described in DOE-HDBK-3010-94[4] used to determine the ARF for burning of packaged combustible waste is conservative for the case being analyzed here.

- Gram quantities were used in the experiments rather than kilogram quantities in the RH waste containers. The gram quantities of material in the experiments did not provide the depth of burn residue that may attenuate the airborne releases from large quantities of material. The waste in the waste drums in this analysis is representative of large quantities of material (up to 1000 lbs (454 kg) per drum). Additionally, the packaging of the waste in a DOT Type A container will limit the area of the waste material exposed to the flame. The experiments described in DOE-HDBK-3010-94[4] used to determine the CARF for combustible packaged waste are conservative for the accidents analyzed in this SAR.

- The radionuclides in the experiments were freshly applied and emphasized the goal of maximizing release. The experimental configuration did not allow the contaminant material to attain the degree of adhesion and packing expected for real stored waste and are, therefore, conservative for the accidents analyzed here.

- The experimental configuration, from which the ARF values were obtained, consisted of burning pre-contaminated wastes packaged in plastic bags, sealed in an 18 in x 18 in x 24 in cardboard box on a grill in a 10 ft diameter by 10 ft high stainless steel vessel. In the accidents analyzed here, the volume in which the fire occurs is the Hot Cell which is much larger than the steel vessel used in the experiments.

- The ARF in DOE-HDBK-3010-94[4] does not include the effects of deposition. Since the Hot Cell has significant deposition surface area, deposition of any particulates generated in the fire may be significant. Therefore, the ARF in DOE-HDBK-3010-94[4] is conservative for the accidents analyzed here.

Even though the bounding value of 5.00E-04 for the ARF has the above conservatisms, it was used in the analysis to ensure adequate margin in the results.

The bounding ARF value of 6.00E-03 for the non-combustible solid waste material, is taken directly from page 5-5 of DOE-HDBK-3010-94.[4]

Median ARFs can also be used to calculate the Source Term for onsite assessments (although the more conservative bounding values were used in this analysis). The median ARF for a combustible material in a waste container is 8.00E-05. No median ARF for a noncombustible material is provided in DOE-HDBK-3010-94[4]. Both combustible and noncombustible ARFs for liquids in a chemical release are set equal to 1.0.

The bounding RFs for burning contaminated packaged mixed waste and the heating of noncombustible contaminated surfaces are 1.0 and 1.0E-02, respectively (DOE-HDBK-3010-94, subsection 5.2.1.1 and 5.3.1).[4] The RF for combustible and noncombustible liquid hazardous materials are both set equal to 1.0. Since the liquids are assumed to vaporize under the thermal stress of the fire, all of the material vaporized will be respirable.

The ARF for contaminated combustible materials, subjected to impact and breach of a waste drum or canister, is 0.001. This value represents a bounding ARF for packaged material in a drum or canister which fails due to impact (DOE-HDBK-3010-94, subsection 5.2.3.2).[4] The bounding RF applied to airborne combustible material released due to impact is 0.1 (DOE-HDBK-3010-94, subsection 5.2.3.2).[4] The ARF and RF for combustible waste forms are conservatively applied to the combustible fraction of material for accident consequence analyses for the waste drum or canister impact or drop scenarios.

The ARF for contaminated non-combustible materials, subjected to impact and breach of the waste canister for solids that do not undergo brittle fracture, is 0.001. This value represents a bounding ARF for packaged material in a canister which fails due to impact (DOE-HDBK-3010-94, subsection 5.3.3.2.2).[4] The bounding RF for contaminated non-combustible materials, subjected to impact and breach of the waste drum or canister, is 1.0 (DOE-HDBK-3010-94, subsection 5.2.3.2).[4] Therefore, the ARF and RF for non-combustible waste forms are conservatively applied to the non-combustible fraction of material for accident consequence analyses for the waste drum or canister impact or drop scenarios.

The aerodynamic entrainment and resuspension of the waste material is not considered because should an accident involving a breach of a waste canister occur, the plant design permits the immediate cessation of activity and isolation of the area where the breach occurs. Once isolation is achieved, there is no driving force within the waste or waste handling area that could result in a further release of the waste material. In order to ensure protection by the identified SSCs during recovery from an event that breaches a waste canister, the Defense-In-Depth SSCs for the waste handling mode will be required during the period of time that waste may be exposed.

For the explosion inside a waste drum accidents, for both the combustible and non-combustible solid waste, ARFs for both the initial explosion and the follow-on fire are required. For combustible waste, page 5-3 of DOE-HDBK-3010-94[4] lists a bounding ARF of 1E-03 for combustible waste exposed to the shock and blast effects of an explosion. For the non-combustible waste, the ARF depends on pressurization that occurs due to the explosion. Since the initial explosion in this event occurs in the head space of a waste drum, pressurization of the drum will occur. However, based on the design of the drums, the likelihood that the lid will fail due to pressurization, and previous analysis of CH waste drums, it is assumed that the drum does not pressurize beyond 25 psig. Therefore, from page 5-6 of DOE-HDBK-3010-94[4], the ARF for non-combustible contaminated material exposed to the blast and shock effects of an explosion at a pressure less than 25 psig is 5.0E-03. (Note that there is a typographical error on page 5-6 of DOE-HDBK-3010-94[4]. It lists the ARFs for pressurization less than and greater than 25 psig. The values in DOE-HDBK-3010-94[4] are reversed. The ARF of 5.0E-03 is correct for pressures less than 25 psig. (This error also applies to the RF.)

For the follow-on fire, the ARFs determined to apply to the fire event previously discussed are assumed to apply to the follow-on fire.

Median ARFs can also be used to calculate the Source Term for onsite assessments (although the more conservative bounding values were used in this analysis). The median ARF for a combustible material in a waste container exposed to the thermal effects of a fire is 8.0E-05. DOE-HDBK-3010-94[4] does not provide the median ARF for a non-combustible material exposed to a fire or for combustible or non-combustible material exposed to the shock and blast effects of an explosion. Therefore, the bounding values are used for those materials in the calculation of the median on-site source term and consequences. For liquids in a chemical release, the ARF is set equal to 1.0. Again, the liquids are assumed to be released in the fire.

The RFs for the combustible solids and non-combustible solids for the explosion accident scenarios are taken directly from DOE-HDBK-3010-94[4]. For the initial explosion, the RF for the combustible material is 1.0 (page 5-3) and the RF for the non-combustible material is 0.4 (page 5-6). For the follow-on fire, the RF for the combustible material is 1.0 (page 5-1) and the RF of the non-combustible material is 0.01 (page 5-5). For the liquid hazardous materials for the follow-on fire, the RF is set equal to 1.0. Since the liquids are assumed to vaporize under the thermal stress of the fire, all of the material vaporized will be respirable.

Leakpath Factor (LPF)

Specific source terms for the postulated accident scenarios described in the accident analysis represent the total amount of respirable radioactive material released to the environment from a postulated accident. The LPF for WIPP accident scenarios is that fraction of the airborne material released in the WHB that is not filtered out by the permanently installed continuously on-line two-stage HEPA filtration system, or for Underground releases, by the Underground exhaust HEPA filtration system when shift to filtration is actuated manually or automatically. Based on the discussion in Section A.3.2 of Appendix A of DOE-STD-3009-94,[1] realistic values are acceptable for estimation of the LPF. Credit for HEPA filtration is taken during the evaluation of the consequences for a mitigated accident. The amount of material removed from the air due to the HEPA filters is based on decontamination factors (DF). DFs have been predicted for accident conditions in ERDA Nuclear Air Cleaning Handbook.[14] Based on the handbook, a DF of 5.0E+02 for the first stage and 2.0E+03 for the second stage are recommended. The total DF used in this analysis for both stages of filtration is 1.0E+06. The LPF is 1.0E-06 for the mitigated case, and 1.0 for the unmitigated case.

The LPF assumed for the release of the non-radiological hazardous material is 1.0 (mitigation is not assumed). However, for fire scenarios, a LPF of 0.5 is assumed to apply to the release of liquid mercury vaporized by the fire. The LPF due to the HEPA filters is only applicable to the material released as particulates. The liquid hazardous material is vaporized due to the thermal stress of the fire. The HEPA filters are not effective in removing vapor. Plateout is one mechanism that removes some of the vaporized material from the air. Plateout is essentially condensation of the vapor back to its liquid form as the air temperature cools or the vapor encounters cooler surfaces. The fire accident analysis for the WIPP CH TRU Central Characterization system[13] contains an analysis of the impact of plateout on the mercury vaporized due to the thermal stress of a fire. Based on that analysis, a conservative LPF value of 0.50 for the plateout of mercury is used. All of the other liquid hazardous materials in the waste except PCBs have much lower boiling points than mercury (40 to 120 °C vs. 357 °C for mercury). Therefore, the other non-PCB liquid materials will not condense out of the air until much lower air temperatures are reached. The LPF for the non-mercury liquid hazardous materials is set to 1.0. The LPF for the PCBs is also conservatively set to 1.0.

Dispersion Modeling Methodology

Nuclear Regulatory Guide (NRG) 1.145,[15] "Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants," methodology was used to develop the atmospheric dispersion coefficients to assess accidental releases from the WIPP Underground exhaust shaft and the WHB exhaust vent. NRG 1.145[15] provides an NRC acceptable methodology to determine site-specific relative concentrations, χ/Qs, and the model reflects experimental data on diffusion from releases at ground level at open sites and from releases at various locations on reactor facility buildings during stable atmospheric conditions with low wind speeds.

The relative concentration value or the atmospheric dispersion coefficient (χ/Q) is the time integrated normalized air concentration at the receptor. It represents the dilution of an airborne contaminant due to atmospheric mixing and turbulence. χ/Q is the ratio of the average contaminant air concentration at the receptor to the contaminant release rate at the release point. It is used to determine the dose consequences for a receptor based on the quantity released (i.e., the source term), atmospheric conditions, and the distance to the receptor of interest.

The atmospheric dispersion coefficient, χ/Q, is a ratio of the air concentration, χ, to the release rate, Q. The χ/Q values in this report were generated using a computer program called GXQ[16]. The GXQ program has been verified to produce χ/Q values consistent with NRG 1.145[15] methodology. The GXQ program used WIPP site specific three-year averaged meteorological data (1996-1999) obtained at the site meteorology tower. All GXQ atmospheric dispersion coefficients were generated using the methods described in the NRG 1.145[15] regulatory position 3, as recommended in Section A.3.3 of Appendix A of DOE-STD-3009-94[1]. The only correction for which credit is taken in the GXQ model is for building wake and plume meander, as described in the NRG 1.145[15] model. This approach is conservative because these corrections theoretically increase the airborne concentration at the downwind receptor locations.

Two types of release models are provided in NRG 1.145:[15] (1) releases through vents or other building penetrations; and (2) stack releases. All release points or areas that are effectively lower than 2.5 times the height of adjacent solid structures are considered nonstack releases. Release points that are at levels 2.5 times the height of adjacent solid structures or higher are considered stack, or elevated releases. Applying this criteria to the WIPP underground exhaust shaft and the WHB exhaust vent, the releases are considered as nonstack releases.

Onsite receptors are assumed to be located 328 ft (100 m) from the release point. The site boundary χ/Q values are based on the distance from the release point to the WIPP Site boundary (see Figure 5.2.1), and exclusive use χ/Q values are based on the distance from the release point to the Exclusive Use Area boundary (see Figure 5.2.2). For assessing the consequences of postulated accidental releases from the Underground exhaust or the WHB, the following conditions are assumed:

1. NRG 1.145[15], Releases through Vents or Other Building Penetrations release model, regulatory position 1.3.1
2. Atmospheric Conditions
   - WIPP Site three-year averaged meteorological data
   - A-F stability
3. Dimensions (smallest cross section) of the Filter Building and the WHB:
   - Filter Building - 23 ft (7 m high), 88.6 ft (27 m) wide
   - WHB - 63 ft (19.2 m) high, 157 ft (47.8 m) wide

The GXQ program produced the following atmospheric dispersion coefficients (χ/Q) (s/m^3); [17]

Distance	Underground Exhaust	WHB Exhaust
328 ft (100 m)	4.50E-03	5.07E-03
Exclusive Use	4.21E-04	4.00E-04
Site Boundary	2.91E-05	2.98E-05

Consequence Methodology

Consequence assessment calculations are determined for the: (1) MEI located at the Exclusive Use Area boundary and (2) the non-involved worker (328 ft [100 m]) for releases from the WHB vent and the exhaust shaft vent. Atmospheric transport is the only significant release and exposure pathway during normal operations and accident conditions during the disposal phase. Based on the site characteristics information in Chapter 2, surface water and groundwater transport from normal or accidental releases of radioactive material is not considered likely. Human exposure pathways from the airborne radioactive material include inhalation, air immersion, ingestion, and ground-shine. Radiological dose consequences are calculated assuming the inhalation pathway in Committed Effective Dose Equivalent (CEDE) and are calculated using Equation 5-5.

External (ground-shine and air immersion) and ingestion dose calculations are not performed due to their minimal contribution to the Total Effective Dose Equivalent (TEDE). Section A.3 in Appendix A of DOE-STD-3009-94[1] states that the airborne pathway is of primary interest in the non-reactor nuclear facilities, therefore CEDE will be reported as the dose consequences for each accident evaluated. The calculated dose in CEDE is then compared to the non-involved worker and MEI radiological risk evaluation guidelines discussed in Section 5.2.2 (Tables 5.2-4a).

For non-radiological consequence calculations, the chemical concentration at the MEI and non-involved worker in mg/m^3 is calculated using Equation 5-6 for comparison with the non-radiological risk evaluation guidelines discussed in Section 5.2.2 (Table 5.2-2).

Detailed spreadsheets for the source term and consequence calculations for each postulated accident are found in Appendix E and summarized in Tables 5.2-3a, 5.2-3b, 5.2-4a and 5.2-4b. To assess the potential releases of radiological and non-radiological material the following equations were utilized:

Radiological Releases

$$\mathbf{D = Q * \chi/Q * BR * DCF} \qquad \mathbf{(5\text{-}5)}$$

where:

D	Radiological dose (CEDE) (rem)
Q	Radiological Source Term (Ci)
χ/Q	Atmospheric dispersion coefficients calculated for specific distances (s/m^3).
BR	Breathing rate (standard man) (m^3/s) International Commission on Radiological Protection (ICRP) No.23[18] (Light activity 5.3 gallons/min [20.0 liters/min or 3.33 E-04 m^3/s]
DCF	Dose Conversion Factor (rem/Ci) Internal Dose Conversion Factors for Calculation of Dose to the Public[19] (Pu-239 Class W CEDE Inhalation 5.1E+02 rem/uCi or 5.10E+08 rem/Ci)

Chemical Releases

$$\mathbf{C = (Q * \chi/Q)/RR} \qquad \mathbf{(5\text{-}6)}$$

where:

C	Concentration (mg/m^3)
Q	Chemical Source Term (mg) (Tables 5.1-2 and 5.1-3)
RR	Release time - VOC releases assumed as instantaneous (1 sec), for potential fire scenarios assumed a release duration of 900 sec
χ/Q	Atmospheric dispersion coefficients calculated for specific distances (s/m^3).

According to the Chemical Assessment methodology, an unmitigated peak 15-minute (900 seconds) average chemical concentration is compared against the guidelines found in Toxic Chemical Hazard Classification and Risk Acceptance Guidelines for the use in DOE Facilities [20]. The actual release of chemicals during an explosion would occur in a much shorter duration (a second or less). The VOCs are assumed to be released instantaneously for the waste drum breach accidents.

Frequency Determination Methodology

The methodology for verifying the annual occurrence frequencies, qualitatively estimated in the HAZOP, of operational initiating events is based on the evaluation of process events, human error, and equipment failures. Section 5.2.3 and Appendix D contain the detailed assessment of occurrence frequencies of the accidents evaluated. Table D-1 presents the estimated occurrence frequencies for process events, equipment failures, and human errors, based on existing references and engineering judgement. The table provides cross references to documents from other DOE sites with similar operations, and from generic industry data bases that have been judged to be applicable and appropriate for use in WIPP accident scenarios.

Equipment failure rates and human error probabilities were combined with WIPP specific operational data to obtain WIPP specific initiating event occurrence frequencies. The individual scenario is discussed in Section 5.2.3, and the supporting detailed event tree/fault tree analysis for each postulated accident is included in Appendix D.

The annual occurrence frequencies derived from the event tree/fault tree analysis are not intended to represent detailed probabilistic calculations requiring sensitivity or uncertainty analysis. They are used to provide reasonable assurance that each scenario's accident frequency is in a specific qualitative frequency range or "bin" for the purposes of selecting an appropriate risk evaluation consequence guideline.

To estimate the occurrence frequencies, logic models were used to describe combinations of failures that can produce a specific failure of interest (TOP event). The logic is developed and explained in Section 5.2.3. The basic events documented in Table D-1 provide specific component failure or human error rates which provide input to the logic model to calculate the frequency of the TOP event. Logical AND (*) or OR (+) functions (gates) are used to show how events can combine to cause the TOP event. The TOP event is quantified in the top row of the appropriate table, with the equation delineating the logic by which it was developed and any necessary comments. Each contributor to that equation is then developed in subsequent rows, using references as necessary to the basic events documented in Table D-1 to complete the line of reasoning. The basic event probabilities were taken either from Table D-1or the generic probability databases developed for Savannah River Site.[32]

5.2.1.2 Immediate Worker Accident Assessment Methodology

The assessment of the immediate worker accident consequences is based on the evaluation of operational waste handling scenarios, whose frequency is greater than 1E-06/yr, that may be initiated by waste handling equipment failure or directly through human error by a worker performing a waste handling operation. The immediate worker is that individual directly involved with the waste handling operation for which the accident is postulated. Although procedures dictate that workers exit the area immediately, such accidents present an immediate risk due to the inhalation of airborne radionuclides to the worker performing the waste handling operation.

Receptors

The majority of the accidents analyzed for the 10-160B cask processing operations occur in either the Cask Unloading Room (CUR), the Hot Cell, or the Transfer Cell. These areas involve only remote handling operations. Workers are not present in these rooms when waste is present. Therefore, there is no possibility of immediate worker exposure for accidents that occur in these rooms. The only accident scenarios that could result in the exposure of immediate workers for 10-160B cask processing are those that occur in the RH Bay where the cask is received, inspected and the lid bolts are loosened. Immediate worker consequences are only considered for the accident scenarios that occur in the RH Bay for 10-160B cask processing.

Evaluations of situations such as disabled worker scenarios, are not performed for the type of accident breach scenario being analyzed (10-160B cask drop or puncture in the RH Bay or grapple hoist drop). Based on the HAZOP results and the accident scenario descriptions in Section 5.3, the conditional likelihood of scenarios involving a worker failing to follow procedure to leave the area immediately, or a coincident worker (immediate waste handler) injury during the drop scenario or the puncture scenario, are extremely unlikely compared to receiving a survivable, specified radiological consequence. The frequency of the scenario analyzed plus conditional likelihood of failing to follow procedure or immediate worker injury would be beyond extremely unlikely.

For the assessment of consequences to workers in the Underground accident scenarios, due to: (1) the ventilation flow path in the Underground disposal rooms and exhaust drifts, and (2) the waste emplacement process (Section 4.3), the receptor of concern is a hypothetical worker who may be in the exhaust drift at the time a RH waste handling accident occurs. WIPP procedure WP 04-AD3013, Underground Access Control[22], prohibits personnel access to the disposal area exhaust drift during waste handling operations. For the Underground waste canister breach scenarios, due to the high ventilation flow rate the workers are conservatively assumed to be exposed to the entire contaminated volume of air before exiting the area. With an assumed exhaust drift velocity of 2 ft (0.6 m) per second (assuming a flow rate of 883 ft^3 [25 m^3] per second and exhaust drift dimensions of 33 ft x 13 ft [10 m x 4 m]), it is conservatively assumed that workers are exposed to the undiluted radioactive cloud at a normal working breathing rate for one second.

For fire release scenarios, due to the extended release time (900 seconds assumed), and the assumption that worker exposure in both the WHB and Underground is for a period of 10 seconds, the accident scenario source terms for the fire scenarios are adjusted by the factor: (exposure time / release time) or (10 secs/900 secs).

Source Term Methodology

The accident scenario specific source term for immediate worker accident assessments is the "no-mitigation" source term developed for the noninvolved worker and MEI accident assessments.

Frequency Determination Methodology

The frequency of each accident analyzed for immediate worker consequences is the "no mitigation" frequency in each detailed event tree/fault tree analysis for each postulated accident is included in Appendix D.

Consequence Modeling Methodology

The onsite and offsite dose model (Equation 5-5) is modified for immediate worker consequence assessment as follows:

Radiological Releases

$$D = (Q * T * BR * DCF)/V \qquad (5\text{-}7)$$

where:

D Radiological dose (Committed Effective Dose Equivalent (CEDE)) (rem)

Q Radiological Source Term (Ci) (Appendix E)

T Exposure Time (1 sec)

BR Breathing rate (standard man) (m^3/s) International Commission on Radiological Protection (ICRP) No.23[18] (Light activity 5.3 gallons/min [20.0 liters/min or 3.33 E-04 m^3/s])

DCF Dose Conversion Factor (rem/Ci) Internal Dose Conversion Factors for Calculation of Dose to the Public[19] (Pu-239 Class W CEDE Inhalation 5.1E+02 rem/uCi or 5.10E+08 rem/Ci)

V = Volume in which radionuclides are released (m^3)

For breach of waste canister due to drop, the release in the WHB occurs in the Transfer Cell. No immediate worker consequences are calculated for this scenario because the operation is done remotely and there are no immediate workers in the Transfer Cell. Additionally, the Transfer Cell is maintained at negative pressure relative to the surrounding areas so that ventilation flows into the Transfer Cell.

This model is further modified to account for the expanding nature of the contamination "cloud" within the WHB. The expanding cloud model modifies the above equation as follows:

$$\mathbf{V = 2/3\pi r^3} \qquad \mathbf{(5\text{-}8)}$$

where:

V Volume of hemisphere of air (m^3)

r Radius of hemisphere = a * t

a = cloud expansion rate, 0.82 ft/s (0.25 m/s)
t = time after accident (seconds)

therefore:

$$\mathbf{V = 2/3\pi(a * t)^3 = 2/3\pi a^3t^3} \qquad \mathbf{(5\text{-}9)}$$

Substituting the above equation for V into the earlier equation 5-7 and integrating with respect to time results in the following:

$$\mathbf{D = (Q * BR * DCF) * [3/(4\pi a^3)] * (T_1^{-2} - T_2^{-2})} \qquad \mathbf{(5\text{-}10)}$$

where:

T_1 = Time cloud is encountered by the immediate worker (seconds)
T_2 = Time the exposure ends (the time the worker leaves the immediate area) (seconds)

In this analysis, the event scenarios involving potential exposure to workers in the immediate area occur in the RH Bay cask receiving area. The source term release cloud generated by the breach of the waste drums contained in a 10-160B cask is modeled as a hemisphere expanding at the ventilation flow rate. It is assumed that the ventilation system in the RH Bay cask receiving area will maintain a flow rate of 0.25 m/sec. For the breach of a 10-160B cask, the initial cloud is assumed to have the same volume as the volume of the 5 waste drums in the 10-160B cask that are subject to damage or 275 gallons or (275 gallons * 0.00378 m^3/gallon =) 1.04 m^3. Assuming the initial cloud is in the shape of a hemisphere, the radius of the initial cloud is $((3/2 * 1.04\ m^3)/\pi)^{0.33}$ =) 0.794 m. At 0.25 m/sec, it will take approximately 3 seconds for the initial cloud to form (for the material to be released from the waste drums and 72B cask). It is assumed that the nearest worker to the 10-160B cask at the time of the breach is three meters from the cask. Therefore, it will take (3 m/0.25 m/s =) 12 seconds for the cloud to reach the nearest worker. The total time from the accident to the initiation of the exposure to the worker is (3 s + 12 s =) 15 seconds. For this analysis, it is assumed that after a release has occurred (after the accident has initiated) the immediate workers will identify that the release is occurring and leave the immediate area within 30 seconds. The 30 second time period is the same as that used in the WIPP CH SAR accident analysis[6]. The 30 seconds is based on 10 seconds to stop the waste handling activity once the accident has occurred and 20 seconds to examine the cask or drums and determine a breach has occurred and begin to exit from the area. The 30 second time frame specifically excludes a disabled worker scenario (a worker injured by the accident). Therefore, the worker will be exposed to the cloud from 15 seconds (T_1 in the equation 5-10) when the cloud reaches him to 30 seconds (T_2 in the equation 5-10) when he leaves the area. Substituting these values into the above equation and reducing:

$$\mathbf{D = (Q * 3.33E\text{-}04\ m^3/s * 5.1E{+}08\ rem/Ci) * [3/(4\pi(0.25\ m/s)^3)] * ((15\ s)^{-2} - (30\ s)^{-2})} \qquad \mathbf{(5\text{-}11)}$$

$$\mathbf{D = Q\ (Ci) * 8.65E{+}03\ (rem/Ci)} \qquad \mathbf{(5\text{-}12)}$$

This is the form of the consequence equation that will be used in this analysis to determine the radiological dose to the immediate worker due to the accidents occurring while processing a 10-160B cask.

For the assessment of consequences to workers in the Underground, the source term is assumed to be released instantaneously into a slug of air with a volume of 850 ft^3 (24 m^3). This volume is based on an instantaneous release and the assumed ventilation flow rate of 2 ft [0.6 m] per second, and the dimensions of the underground exhaust drift, or

$V = (2\ ft/s\ [0.6\ m/s]) * (1\ sec) * (33\ ft\ [10\ m]) * (13\ ft\ [4\ m]) = 24\ m^3$.

A volumetric flow of 25 m^3 was used for the assessment of consequences to the workers in the Underground and for Waste Hoist accidents.

5.2.2 Off-site and On-site Risk Evaluation Guidelines

The evaluation guidelines that are established should not be regarded as a "bright line" criterion and doses challenging the guidelines or in the rem range should indicate the need to consider classifying preventative or mitigative SSCs as safety class.

Guidelines do not exist for the frequency range of beyond extremely unlikely (frequency $\leq$ 1E-06/yr). The consequences of accidents in that range are conservatively evaluated against the guidelines for the extremely unlikely range for the sole purpose of evaluating the risk associated with facility operations.

5.2.2.1 Radiological Risk Evaluation Guidelines

Off-site radiological dose criteria for accident analyses have been well established by national standards through the licensing process of nuclear facilities regulated by the NRC. These criteria are based on the probabilities of occurrence of the accidents or events hypothesized for the accident analysis. For nuclear power plants, the operational accidents or events are classified as Plant Conditions (PC) in accordance with the estimated frequency of occurrence.[23, 24] This established scheme (ANSI/ANS-51.1)[23] has been adopted by the WIPP to compare accidental releases from postulated events to dose limits based on estimated frequency of occurrence. Table 5.2-1a summarizes the risk evaluation guidelines for the assessment of off-site radiological exposures.

The same approach is used for the on-site risk evaluation guidelines as for the off-site (public) dose. The on-site risk evaluation guidelines are greater than those for the public by assuming that entry onto the site implies acceptance of a higher degree of risk than that associated with the off-site public. This assumption is not considered remiss with regards to safety assurance because the on-site risk evaluation guidelines do not result in any health effects noticeable to exposed individuals at frequencies greater than 1 E-4 event per year and would not result in any acute life-threatening effects.

For accidents with an estimated frequency between 1E-1 and 1E-2 event per year, the limit is 5 rem (50 mSv) based on the allowable yearly worker exposure limits cited in 10 CFR 835.[25] For the estimated frequency range of 1 E-2 to 1 E-4 event per year, the threshold is 25 rem (250 mSv) for the same reason the NRC provided in 10 CFR 100[26] for using it for design basis reactor accident calculations (value at which no significant health effects result).

Accidents with an estimated frequency range of 1 E-4 to 1 E-6 event per year have a limit of 100 rem (1 Sv). The DOE Emergency Management Guide for Hazards Assessment[27] uses 100 rem (1 Sv) whole body exposure as a threshold for early severe effects. It also acknowledges that early severe effects would not actually be experienced for a 50-year *dose* of 100 rem (1 Sv) due to alpha emitters.

5.2.2.2 Non-radiological Risk Evaluation Guidelines

DOE orders do not contain a unique set of approved non-radiological risk evaluation guidelines. The WIPP non-radiological risk guidelines are based on Emergency Response Planning Guidelines (ERPGs) published by the American Industrial Hygiene Association (AIHA). ERPGs are estimates of concentration ranges for specific chemicals above which acute (< 1 hour) exposure would be expected to lead to adverse health effects of increasing severity for EPRG-1, -2, and -3. The definitions of ERPGs are:

ERPG-1 The maximum concentration in air below which it is believed nearly all individuals could be exposed for up to one hour without experiencing other than mild transient adverse health effects or perceiving a clearly defined objectionable odor.

ERPG-2 The maximum concentration in air below which it is believed nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair their abilities to take protective action.

ERPG-3 The maximum concentration in air below which it is believed nearly all individuals could be exposed for up to one hour without experiencing or developing life-threatening health effects.

ERPGs have been developed for approximately 100 chemicals and do not exist for some of the chemicals found in TRU mixed waste. Chemicals without established ERPG values will use Temporary Emergency Exposure Limits (TEELs) developed by the DOE Emergency Management Advisory Committee's Subcommittee on Consequence Assessment and Protective Action (SCAPA), Revision 18, Table 4. SCAPA developed TEELs to allow for the preliminary identification of hazardous or potentially hazardous situations for emergency planning even when ERPGs were not available. The TEEL is an interim parameter meant to approximate an ERPG so that emergency planning and preparedness activities can be conducted. Whenever an ERPG is developed for a new chemical, the ERPG replaces the TEEL. The definitions of TEELs are:

TEEL-0 The threshold concentration below which most people will experience no appreciable risk of health effects;

TEEL-1 The maximum concentration in air below which it is believed nearly all individuals could be exposed without experiencing other than mild transient adverse health effects or perceiving a clearly defined objectionable odor.

TEEL-2 The maximum concentration in air below which it is believed nearly all individuals could be exposed without experiencing or developing irreversible or other serious health effects or symptoms that could impair their abilities to take protective action;

TEEL-3 The maximum concentration in air below which it is believed nearly all individuals could be exposed without experiencing or developing life-threatening health effects.

The chemicals and hazardous materials in the RH waste that do not have ERPG values will substitute the TEEL value in lieu of the ERPG value:

ERPG-1 TEEL-1

ERPG-2 TEEL-2

ERPG-3 TEEL-3

5.2.3 Accident Analysis

5.2.3.1 RH1 Fire in the Underground

Scenario Description - The HAZOP[28] postulated a waste canister breach from a fire in the Underground facility. The HAZOP postulated two hazardous events (9-7 and 10-2) that could result in a fire in the Underground facility which could cause a significant release of radioactivity.

Hazardous event 9-7 postulates a diesel fuel fire on forklift during the transfer of facility cask to disposal room. The forklift usually has about 20 gal (75.7 L) of diesel fuel. The cause of this event is a diesel fuel leak. An ignition source could ignite the fuel and cause a fire. The fire could potentially damage the facility cask and waste canister and cause a breach of the waste canister because neither the facility cask or the waste canister are qualified for a fire. The thermal stress on the breached waste canister could cause a significant release of radioactivity. The immediate worker(s) could also receive a significant direct radiological exposure from the breached waste canister.

The hazardous event 10-2 postulates a hydraulic oil fire on the Horizontal Emplacement and Retrieval Equipment (HERE) during emplacement of the waste canister in the borehole. The HERE usually has about 40 gal (151.4 L) of hydraulic oil.[29] The cause of this event is a hydraulic oil leak. An ignition source could ignite the hydraulic oil and cause a fire. According to Material Safety Data Sheet (MSDS), the hydraulic oil is slightly flammable (NFPA rating of 1).[30] The fire could potentially damage the facility cask and waste canister and cause a breach of the waste canister because neither the facility cask or the waste canister are qualified for a fire. The thermal stress on the breached waste canister could cause a significant release of radioactivity. The immediate worker(s) could also receive a significant direct radiological exposure from the breached waste canister.

Preventive and Mitigative Features - General preventive and mitigative measures identified in the HAZOP for this specific scenario are listed in Table 5.1-10.

Estimated Frequency - The HAZOP Team qualitatively estimated the frequency of occurrence of a fire in a waste canister in the Underground facility to be in the anticipated range ($10^{-1} \geq$ frequency$>10^{-2}$) for both the hazardous events. However, based on a quantitative evaluation using conservative assumptions documented in Appendix D and below, the overall frequency of breach of waste canister due to fire from forklift operations in the Underground (event 9-7) is beyond extremely unlikely (frequency $\leq 10^{-6}$/yr). Risk evaluation guidelines are not identified for events with frequency $\leq 10^{-6}$/yr.

The *Source Term Development* will show that there is no release from event 9-7, however, the frequency of the fire is calculated in Table D-1 for reference in the BDBA scenario, RH 5. This section discusses the evidence and reasoning used to develop and quantify the frequency. The scenario is initiated by a diesel fuel leak from the forklift. An ignition source of sufficient magnitude is needed to start a fire. A sustained fire could then cause a breach of waste canister contained in a facility cask. The quantification of each of these contributors is:

1. Frequency of leak or collision accidents in the Underground

The frequency of leak or collision accidents in the Underground is 3.3E-03/yr. It is a product of the number of forklift operations per year (N_forklift_UG) times the probability of puncture events during waste handling operations in the Underground (f_punct_UG). The conservative throughput of waste canisters is 693/year which translates to 693 forklift operations per year (693 op/yr). The puncture events can happen through human error or hardware failure. Therefore, the probability of puncture events of 6.4E-06 /op is a sum of human error events and hardware failure events. The probability of collision due to human error (H_forklift_punct) of 5.0E-06/op is obtained from the Savannah Rive Site Model.[31] A low value is used because the forklift is used in a consistent and repetitious manner for waste transfers. The forklift transfer in the Underground is a standard operation done under excellent working conditions and a spotter is present. The disposal room floor will be leveled prior to waste operations in the room. Forklift hardware failures (f_hardware) of 1.4E-06/op result from time related mechanisms during operation, but collisions or fuel leaks during the time when the forklift is handling waste could result in releases. The frequency of failures is based on study done at Idaho National Engineering Laboratory (INEL) on forklift equipment failures producing punctures. Also included in the forklift hardware failures is the frequency of leaks in the fuel tanks. The frequency of a tank leak is based on a generic tank and is conservative.[21] The tanks on the forklifts are more reliable because they conform to MSHA requirements. It is conservatively assumed that all puncture events could result in diesel fuel leak.

2. Probability of fire after a forklift collision or leak

The conditional probability of fire, given an Underground forklift accident is 5.0E-04. This is based on the probability for fire, given a bus accident, as reported in Table 38 of WSRC-TR-93-581.[31] The data used in this reference encompasses highway speeds and vehicles with gasoline engines as well as diesel. It is judged that the "Bus" sub-population is more closely aligned with forklifts than trucks, cars, or other/unknown vehicles.

3. Probability that a waste canister is breached, given a fire adjacent to the waste canister

The estimate for this event uses the waste drum fire propagation study results[32] considering four failure modes: 1) breach by metal deformation, 2) internal gas content expansion, 3) decomposition of contents, and 4) contents are volatile. The fire propagation study assigned a likelihood of 0.001 to each of these failure modes. To account for the more energetic burning of an exterior fire, the failure likelihood was increased by a factor of 10 for each failure mode. The likelihood of the individual failure modes sum to yield a total conditional likelihood of 0.04. The waste canister is in a facility cask which provides an additional confinement barrier for waste release as compared to waste drums. Also, the waste canisters are more robust than the waste drums because of their design features. It also assumes that there are no other RH waste canisters or CH waste drums in the path of forklift when RH waste canisters are processed in the Underground.

In order for waste canister breach to occur the above three events have to happen. The frequency of a fire that breaches the waste canister is 6.6E-08/yr (3.3E-03/yr x 5.0E-04 x 4.0E-02). The following evidence, much of which is not explicitly accounted for in the quantification, support this assessment and provide confidence that it is conservative:

- The forklift used to transfer waste canisters from the hoist to the waste rooms in the Underground panels is powered by a diesel engine. It has multiple safety features to reduce the likelihood of fires, such as: (1) fuel tanks segmented into fuel cells, (2) an automatic chemical fire extinguishing system, and (3) electrical parts designed to reduce electric sparks. It is anticipated that any forklift procured to handle waste canisters in the Underground horizon will have similar safety features. These features far exceed those of a typical car, truck, or bus.

- Unloading, transport, and placement of facility casks containing waste canisters on the HERE will be the only operations accomplished with the forklift. These operations are controlled and repeatable. They will be accomplished only by qualified waste handlers, one of which will serve as the forklift operator and another as spotter. As the floor of the active room will be leveled prior to declaring it ready for waste emplacement, the operational conditions will be excellent. The operating philosophy of the plant requires that waste handling be stopped should any abnormal event occur.

- The forklift operations will be done at very slow speeds rather than typical highway speeds. The forklift has 2 speeds, low range at which waste handling operations are performed and high range which is used only when the forklift is not transporting a load.

- No other vehicle movement is allowed in the transport path during RH waste movement or when RH waste is being transported in the Underground.

- Diesel fuel has a high flash point, which makes it difficult to ignite unless the diesel engine operates at higher temperatures to control emissions and the fuel contacts the hot surface of the engine. The data in WSRC-TR-93-581[31] arises from the mix of gasoline and diesel engines.

- The facility cask, waste canister and its contents constitute a considerable thermal sink. In addition, a filtered vent in each 72B waste canister will allow expanding gases within the canister to escape, which will both relieve internal pressure buildup and tend to eliminate oxygen from the interior. Thus, the waste canister will most likely have to be heated to very high temperatures sufficient to induce pyrolysis of the contents to produce a release of hazardous materials that could overwhelm the capacity of the vent filter. It is highly unlikely that the fire can burn long enough for this to occur.

- No credit is taken for the ability of the waste handling team to fight a fire. The forklift will have at least a fire extinguisher aboard, as required by Federal Metal and Nonmetallic Mine Safety and Health Regulations, 30 CFR 57.4260. Personnel will be present who could extinguish the fire even if the operator were injured. As indicated in WSMS-WIPP-99-0002 [33], employees extinguished all five instances of forklift fires at the Savannah River Plant between 1980 and 1995, with little or no resulting damage.

The frequency of hazardous event 10-2 is not calculated because there will be no release of radioactivity from this event as shown by the scoping Thermal Analysis.[33]

Source Term Development - The maximum temperature of the waste canister will be ≤ 500 °F (260 °C) from a potential hydraulic oil fire (event 10-2) as evaluated by scoping Thermal Analysis.[33] The waste canister has a carbon composite filter held in place by AREMCO 503 Ceramabond.[34] The maximum temperature of the Ceramabond is 3000 °F (1649 °C). There will be no appreciable increase in the internal pressure of the waste canister because the filter would stay in place during and after the fire event. <u>There will be no release of radioactivity</u>.

The scoping Thermal Analysis [33] is conservative because:

- The maximum volume of hydraulic oil (40 gals [151.4 L]) available for combustion is the volume analyzed in DOE/WPP-87-005[32].

- The leaked hydraulic oil will form a pool under and around the HERE because there is no catch pan to collect any potential leaks. The leaked hydraulic oil will be absorbed by the salt and there could be a small layer of hydraulic oil on the salt surface. Assuming that there is an ignition source available for hydraulic oil, further spread of flame then depends on heat transfer to the fuel from the hot flame gases, and its movement across the surface is relatively slow[35]. This shows that only a small fraction of the leaked hydraulic oil would burn during a potential fire. Therefore, the heat released from the combustion of leaked hydraulic oil would be significantly less than what is calculated in DOE/WPP-87-005.[32]

- There are no known ignition sources that could ignite hydraulic oil.

Safety Structures, Systems, and Components - Based on the frequency and scoping Thermal analyses for this accident, Safety Class or Safety significant SSCs are not required. The following input data and assumptions are used in the frequency analysis:

- Throughput of waste canisters is 208/year which translates to 208 forklift operations per year.

- There are no other facility casks containing RH waste canisters or CH waste drums in the path of forklift when facility cask containing RH waste canisters are processed in the Underground.

- RH waste canisters are vented.

- A spotter is present when the RH waste canister is transported by the forklift in the Underground.

- Maximum volume of hydraulic oil in the HERE is ≤ 40 gals (151.4L).

The defense-in-depth SSCs which are applicable to this scenario, per the criteria in Chapter 3, Section 3.1.3 are assigned as follows:

- Vented DOT Type A (or equivalent) RH canister - Primary confinement
- Underground Ventilation System - Secondary confinement
- Design of fuel tank on forklift and hydraulic oil reservoir on HERE - Designed to minimize leaks

The defense-in-depth ACs which are applicable to this scenario, per the criteria in Chapter 3, Section 3.1.3 are assigned as follows:

- No other vehicle movement is allowed during RH waste movement in the Underground.

Section 5.2.4.1, Evaluation of the Design Basis, discusses in greater detail: (1) the evaluation of safety SSCs and (2) the applicability of functional and performance requirements (system evaluation) and controls (TSRs). Detailed design descriptions for the above defense-in-depth SSCs may be found in Chapter 4 and the applicable System Design Descriptions.

Source Term Development - A release from event 9-7 is prevented by the following *passive design feature*.

- The W-170 drift leading to the diesel fuel storage area is 14 feet in width. The diesel fuel storage area is over 1000 feet northwest of the waste shaft. The waste handling path to the disposal area runs down the E-140 to the south. The largest bulkhead from the E-140 leading to the W-170 drift is 9 feet in height. The 41 ton Forklift which is used to transport the facility cask is 10 feet 6 inches in height. The design of the bulkhead doors prevent movement of a loaded facility cask to the diesel fuel storage.

In addition to the passive design, multiple administrative controls and active design features are in place to ensure that the quantity of fuel near the facility cask is limited.

- The maximum volume of diesel fuel in the Forklift is $\leq$ 20 gal (75.7 L).
- There is not another facility cask containing a RH waste canister or any CH waste in the path of the forklift transporting a filled facility cask to the disposal room.
- A waste in transit notification system has been installed in the underground to alert personnel when TRU Waste is being transported from the Waste Shaft Collar to the panel area for emplacement. This is a series of amber strobe lights, when they are activated, all personnel in E-140 shall evacuate the drift by going into a crosscut, and remain there until the lights are turned off. However, the amber strobe light notification system **is not** required to be operational as a prerequisite to waste handling activities. The backup notification, if the strobe lights are inoperative, would consist of an announcement by the CMRO, a sweep of the E-140 and S-1950 drifts by the U/G Rover with subsequent verbal notification, and the placement of temporary barriers (bi-folds with signs) in the E-140 drift.

Safety Structures, Systems, and Components - Due to no release from this event, Safety Class or Safety significant SSCs are not required. The following data and assumptions are used in the frequency analysis:

- Throughput of waste canisters is 208/year which translates to 208 forklift operations per year.

- There is not another facility cask containing a RH waste canister or any CH waste in the path of the forklift transporting a filled facility cask to the disposal room.
- 72B waste canisters are vented
- A spotter is present when a RH waste canister is transported by the forklift in the Underground.
- Maximum volume of diesel fuel in the forklift is $\leq$ 20 gal (75.7 L).

The defense-in-depth SSCs which are applicable to this scenario, per the criteria in Chapter 3, Section 3.1.3 are assigned as follows:

- Vented DOT Type A (or equivalent) RH canister - Primary confinement
- Underground Ventilation System - Secondary confinement
- Design of Fuel and Hydraulic Oil Tanks- Designed to minimize leaks

Section 5.2.4.1, Evaluation of the Design Basis, discusses in greater detail: (1) the evaluation of safety SSCs and (2) the applicability of functional and performance requirements (system evaluation) and controls (TSRs). Detailed design descriptions for the above defense-in-depth SSCs may be found in the applicable SDDs as referenced in Chapter 4.

Due to the importance of the WIPP Emergency Management Program,[36] TSR ACs are derived in Chapter 6 and required in the WIPP TSR document.

5.2.3.2 RH2 Fire in the WHB

Scenario Description - The HAZOP[28] postulated a waste canister breach from a fire in the WHB. The HAZOP postulated hazardous event (7-10) that could result in a fire in the WHB. The fire could cause a significant release of radioactivity.

The hazardous event 7-10 postulates a hydraulic oil fire in the Facility Cask Loading Room. The cause of this event is a hydraulic oil leak from the facility cask rotating device. The facility cask rotating device usually has about 40 gals (151.4 L) of hydraulic oil[37]. An ignition source could ignite this fuel and cause a fire. According to the MSDS, the hydraulic oil is slightly flammable (NFPA rating of 1)[30]. The fire could potentially damage the facility cask and waste canister and cause a breach of the waste canister because neither the facility cask or the waste canister are qualified for a fire. The thermal stress on the breached waste canister could cause a significant release of radioactivity. The immediate worker(s) could also receive a significant direct radiological exposure from the breached waste canister.

Preventive and Mitigative Features - General preventive and mitigative measures identified in the HAZOP for this specific scenario are listed in Table 5.1-10.

Estimated Frequency - The HAZOP Team qualitatively estimated the frequency of occurrence of a fire in the WHB to be in the anticipated range ($10^{-1} \geq$ frequency$>10^{-2}$) for the hazardous event 7-10. This frequency is conservative because there are no known ignition sources that could ignite hydraulic oil.

Source Term Development - The maximum temperature of the waste canister will be ≤500 °F (260 °C) from a potential hydraulic oil fire (event 7-10) as evaluated by the scoping Thermal Analysis.[33] The waste canister has a carbon composite filter held in place by AREMCO 503 Ceramabond.[34] The maximum temperature of the Ceramabond is 3000 °F (1649 °C). There will be no appreciable increase in the internal pressure of the waste canister because the filter would stay in place during and after the fire event. <u>There will be no release of radioactivity.</u>

Safety Structures, Systems, and Components - Based on the lack of release of radioactivity as supported by the scoping Thermal Analysis,[33] Safety Class or Safety significant SSCs are not required. The following data and assumptions are used in the thermal analysis:

- Design and Location (>6 ft [1.8 m]) from the catch pans provided for the hydraulic unit of facility cask rotating device) of the facility cask transfer car
- Maximum volume of hydraulic oil in the facility cask rotating device is ≤ 40 gal (151.4 L).
- Capacity of the catch pans in the facility cask rotating device is > 45 gals (170.3 L).

The defense-in-depth SSCs which are applicable to this scenario, per the criteria in Chapter 3, Section 3.1.3 are assigned as follows:

- Vented DOT Type A (or equivalent) RH Canister - Primary confinement
- WHB Structure - Secondary confinement
- WHB RH HVAC System - Secondary confinement
- WHB HEPA Filters - Secondary confinement
- Design of Hydraulic Oil Reservoir - Designed to minimize leaks

Section 5.2.4.1, Evaluation of the Design Basis, discusses in greater detail: (1) the evaluation of safety SSCs and (2) the applicability of functional and performance requirements (system evaluation) and controls (TSRs). Detailed design descriptions for the above defense-in-depth SSCs may be found in Chapter 4 and the applicable SDDs.

Due to the importance of the WIPP Emergency Management Program,[36] TSR ACs are derived in Chapter 6 and required in the WIPP TSR document.

5.2.3.3 RH3 Loss of Confinement in the WHB

Scenario Description - The HAZOP[28] postulated a LOC of the waste material in the WHB. The HAZOP postulated three hazardous events (7-1, 7-2, and 7-6) that could result in a LOC of the waste material in the WHB. The LOC events could cause a significant release of radioactivity.

Hazardous event 7-1 postulates a movement of shuttle car while grapple hoist is lifting the waste canister. The causes of this event are mechanical failure or control loop failure during lifting of the waste canister. The potential consequences of this event are: breach of a waste canister, damage to shuttle car, spread of contamination, direct radiological exposure, radiological impact offsite, and worker fatality. The potential breach of a waste canister could cause a significant release of radioactivity to the environment.

Hazardous event 7-2 postulates a drop of waste canister while being lifted into the facility cask. The dropped canister either falls into the 72B cask or onto the Transfer Cell floor. The causes of this event are human error, equipment failure-hoist or grapple, or control loop failure during lifting of the waste canister. The potential consequences of this event are: breach of a waste canister, significant damage to the facility, spread of contamination, significant process downtime for recovery, and radiological impact offsite. The potential breach of a waste canister could cause a significant release of radioactivity to the environment.

Hazardous event 7-6 postulates a closure of shield valve on waste canister (sooner than desired) while it is being lifted into the facility cask. The cause of this event is control loop failure during lifting of the waste canister. The potential consequences of this event are: breach of a waste canister, damage to shuttle car, spread of contamination, direct radiological exposure, and radiological impact offsite. The potential breach of a waste canister could cause a significant release of radioactivity to the environment.

Preventive and Mitigative Features - General preventive and mitigative measures identified in the HAZOP for this specific scenario are listed in Table 5.1-10. For the no mitigation case, the HEPA filters are assumed to be bypassed or not in place. For the mitigated case, credit is taken for the permanently installed continuously on-line two-stage HEPA.

Estimated Frequency - The HAZOP Team qualitatively estimated the frequency of LOC in the WHB to be in the anticipated range ($10^{-1} \geq$ frequency $>10^{-2}$) for all the hazardous events.

Hazardous event 7-1, movement of shuttle while 6.25-ton grapple hoist is lifting waste canister, is prevented by the following passive design features:

- Hardwired interlock between the shuttle car and the shield valve that allows either the shuttle car or the shield valve to be powered.

Additionally, failure of the active engineered features were quantified in PLG-1317, Waste Isolation Pilot Plant 6.25 Grapple Hoist Fault Tree Analysis,[38] and the frequency of the shuttle car moving while a lift is occurring was calculated to be 3.30E-12 events/lift which makes this event beyond extremely unlikely (10^{-6}/yr $\geq$ frequency).

Hazardous event 7-6, closure of shield valve on waste canister, is prevented by the following *passive design feature:*

- Design of motor on the shield valve will prevent this event.

The calculated frequency of the shield valve crushing the canister from PLG-1317[38] is 2.0E-13 events/lift, therefore, this event is also beyond extremely unlikely (10^{-6}/yr $\geq$ frequency). This accident scenario is evaluated even though <u>no release</u> is postulated because it is prevented by active design features.

Results from the event tree analysis described below are documented in Appendix D (Table D-3), the overall frequency of hazardous event 7-2, drop of waste canister while being lifted into the facility cask in the WHB, is in the beyond extremely unlikely range (10^{-6}/yr $\geq$ frequency).

An event tree analysis has been developed to show the frequency of a failure of the grapple hoist per year.(Appendix D, Table D-3) The frequency of a grapple hoist failure resulting in a breach of the canister was calculated in PLG-1317[38] fault tree analysis.

The fault tree analysis includes the hoist operation of the canister and the primary focus of the analysis was to illustrate the failure mechanisms for the breach of the 72B waste canister during facility cask loading operation in the Facility Cask Loading Room. The prime question in developing this fault tree was what could go wrong during the grapple hoist operation that could lead to waste canister damage and subsequent release of the waste canister contents to the environment. The subsequent question was given these failure mechanisms occur, what would be the likelihood of RH canister breached. In order to develop this fault tree, design information and related documents were gathered, and interviews with the engineering staff were conducted.

The WIPP facility has an aggressive crane test, maintenance, and inspection program which applies to the grapple hoist used to load waste canisters into the facility cask. Some elements of that program are: (1) preoperational checks and inspections of the grapple, wire ropes, lifting, and balancing assembly; (2) no-load test once per shift; (3) monthly inspection of the grapple and wire rope; and (4) yearly nondestructive testing of the hook and wire rope. These provisions provide assurance that the analysis failure rate is very conservative estimate of the frequency of the initiating event for hazardous event 7-2.

The grapple hoist brake system is designed to engage upon loss of power, and as such, hold the load, thus minimizing the probability of waste canister breach.

Based on the results of the event tree analysis, it may be concluded that the frequency of hazard events during use of the grapple hoist system is extremely low. The assessment could not identify improvements to the grapple hoist and the operations associated with it that would significantly lower this frequency.

Source Term Development - The following are two different scenarios that could occur during the lifting of waste canister from the 72B cask in the Transfer Cell into the facility cask in the Facility Cask Loading Room.

- The waste canister is held by the grapple hoist in the Facility Cask Loading Room and the Transfer Cell ceiling shield valve is closed. The waste canister could be dropped by the hoist and could fall on the shield valve.

- The waste canister is lifted from the 72B cask in the Transfer Cell and the Transfer Cell ceiling shield valve is open. The waste canister could be dropped by the hoist and could fall into the 72B cask. There will be no failure of the shuttle car because it is designed to support the drop of waste canister from facility cask into the 72B cask.[39]

In the first scenario, the bottom of the waste canister is $\leq$ 4 ft (1.2 m) from the top of the Transfer Cell ceiling shield valve. The waste canister is designed to maintain the containment integrity of waste material in it if it is dropped from $\leq$ 4 ft (1.2 m). Therefore, there will be no release of waste material from the first scenario.

In the second scenario, the bottom of the waste canister is $\leq$ 22 ft (6.7 m) from the bottom of the 72B cask in the Transfer Cell. A drop of the waste canister from the maximum height of 22 ft (6.7 m) could potentially compromise the confinement integrity of the waste material in it. Therefore, there is a possibility of waste material release from the second scenario.

Radiological Waste Canister Inventory (CI) - Based on the postulated scenario, the CI for this accident has been determined to be the inventory contained in one waste canister. As discussed in Section 5.2.1.1, it is assumed that the waste canister contains the maximum radionuclide inventory of 80 PE-Ci for direct loaded waste and 240 PE-Ci for double contained waste. The waste canister is conservatively assumed to contain 95 percent noncombustible and five percent combustible material as discussed in Section 5.2.1.1.

Non-radiological Waste Canister Inventory (CI) - As discussed in Section 5.2.1.1, the non-radiological CI development process for events which involve a breach of a waste canister is simplified by assuming that 100 percent of the VOC headspace inventory is released instantaneously. VOCs selected for consideration for accidental releases are listed in Table 5.1-2. The weighted average of VOCs in the RH waste is assumed to be the same as in CH waste. The mass of VOC is based on the moles of gas present in the RH waste canister. A void space of 70 percent, same as in CH waste drums, is used for calculating moles of gas present in the 72B waste canister.

Damage Ratio - As discussed in Section 5.2.1.1, for drops of waste canisters from the height associated with crane failure, from heights greater than 4 ft (1.2 m), and equal to or less than 22 ft (6.7 m) (4 ft [1.2 m]$<$ h $\leq$ 22 ft [6.7 m]), are evaluated. Based on the analysis, it is conservatively assumed, to encompass the uncertainty in the application of test data and the variation in waste forms, that the DR for Type A (or equivalent) canisters in this class of accident is 1.0 (DR=1.0) for direct loaded waste and 0.1 (DR=0.1) for double confined waste.

Airborne Release Fraction and Respirable Fraction - As discussed in Section 5.2.1.1, the ARF for contaminated combustible materials which are subjected to impact and breach of the waste canister is 0.001. This value represents a bounding ARF for packaged material in a canister which fails due to impact (DOE-HDBK-3010-94, subsection 5.2.3.2).[4] The bounding RF is 0.1 (DOE-HDBK-3010-94, subsection 5.2.3.2).[4]

The ARF for contaminated noncombustible materials which are subjected to impact and breach of the waste canister for solids that do not undergo brittle fracture is 0.001. This value represents a bounding ARF for packaged material in a canister which fails due to impact (DOE-HDBK-3010-94, subsection 5.3.3.2.2).[4] The bounding RF is 1.0 (DOE-HDBK-3010-94, subsection 5.2.3.2).[4]

Leakpath Factor - Based on the scenario description, it is not expected that the grapple hoist failure in the WHB will also disable the WHB ventilation or HEPA filtration systems. If a grapple hoist failure results in a release to the WHB, the release to the outside environment is mitigated by the permanently installed continuously on-line two-stage HEPA. Although the ventilation system is required to be operational during waste handling operations, active ventilation is not required to prevent a significant release of hazardous materials from the WHB. The intact HEPA filters will maintain the secondary confinement barrier, with a potential for only minor releases via leakage around access shield valves, etc. resulting from the loss of differential pressure.

The amount of material removed from the air due to the HEPA filters is predicted based on decontamination factors (DF). DF have been predicted for accident conditions in ERDA 76-21.[14] Based on the handbook, the total DF used in this analysis for both stages of filtration is 1.0E+06. The LPF is 1.0E-06 for the mitigated case and 1.0 for the unmitigated case.

Estimated noninvolved worker and MEI Consequences and Comparison to Risk Evaluation Guidelines - The accident risk evaluation guidelines for the extremely unlikely range are used for the comparison of the unmitigated noninvolved worker and MEI consequences.

Based on the values for the source term variables, the worst-case, unmitigated MEI and noninvolved worker consequences (Appendix E, Tables E-1, E-2, and E-3) of the LOC in the WHB (RH3) are well within the radiological and non-radiological risk evaluation guidelines for the extremely unlikely range.

Assessment of Immediate Worker Consequences- No immediate worker consequences are calculated for this accident. There are no workers in the Transfer Cell where the release occurs because the operation is done remotely.

Safety Structures, Systems, and Components - Based on the estimated worst-case unmitigated MEI and noninvolved worker consequences and comparison to the risk evaluation guidelines, Safety Class or Safety significant SSCs are not required. The following input data and assumptions are used in the accident analysis:

- Shuttle car is designed to support the drop of waste canister from facility cask into the 72B cask.[39]
- Throughput of waste canisters is 208/year.
- It is assumed that the facility cask loading grapple hoist is as reliable or better than the TRUPACT Crane System.
- Grapple hoist brake system is designed to engage upon loss of power, and as such, hold the load, thus minimizing the probability of waste canister breach.
- The maximum height from which the waste canister could be dropped is ≤ 22 ft (6.7 m).
- Should an accident involving a breach of a waste canister occur, the plant design permits the immediate cessation of activity and isolation of the area where the breach occurs. Once isolation is achieved, there is no driving force within the waste or waste handling area that could result in a further release of the waste material.
- Distance of the grapple hoist operator from the dropped waste canister is 15 ft (4.5 m).

The defense-in-depth SSCs which are applicable to this scenario, per the criteria in Chapter 3, Section 3.1.3 are assigned as follows:

- Vented DOT Type A (or equivalent) RH canister - Primary confinement
- WHB structure - Secondary confinement
- WHB RH HVAC system - Secondary confinement
- WHB HEPA filters - Secondary confinement
- Grapple Hoist - Designed to minimize failure resulting in a dropped load
- Design of 72B cask- Prevents/minimizes releases from the waste canister
- Design of waste canister - Prevents/minimizes releases of waste material

Section 5.2.4.1 discusses in greater detail: (1) the evaluation of safety SSCs, and (2) the applicability of functional and performance requirements (system evaluation) and controls (TSRs). Detailed design descriptions for the above defense-in-depth SSCs may be found in the applicable SDDs as referenced in Chapter 4.

Due to the importance of WIPP programs relating to configuration and document control, quality assurance, conduct of operations, preventative maintenance and inspection, waste handling procedures and training, the WIPP RH WAC, and the WIPP Emergency Management Program[36] and associated procedures, in the WIPP defense-in-depth strategy for this accident, TSR ACs are derived in Chapter 6 and required in the WIPP TSR Document.

5.2.3.4 RH4-A Loss of Confinement in the Underground (Waste Hoist Failure)

Scenario Description - The HAZOP[28] postulated a LOC of the waste canister in the waste hoist (RH4-A). The HAZOP[28] postulated two hazardous waste hoist events (8-4 and 8-6) that could result in a LOC of the waste material in the Underground. The LOC event could cause a significant release of radioactivity.

Hazardous event 8-4 postulates a drop of the facility cask into the shaft because of incorrect waste hoist position. The cause of this event is human error. The potential consequences of this event are : breach of a waste canister, major damage to shaft, significant radiological exposure to personnel, major release of radioactive materials, considerable impact offsite, and worker fatality. The potential breach of a waste canister could cause a significant release of radioactivity to the environment.

Hazardous event 8-6 postulates a drop of waste hoist to the bottom of the shaft during transfer of RH waste canister to the Underground. The cause of this event is equipment failure-brake system. The potential consequences of this event are: breach of a waste canister, major damage to shaft, significant radiological exposure to personnel, major release of radioactive materials, considerable impact offsite, and worker fatality. The potential breach of a waste canister could cause a significant release of radioactivity to the environment.

Preventive and Mitigative Features - General preventive and mitigative measures were identified in the HAZOP for this specific scenario and are listed in Table 5.1-10. For the no-mitigation case, automatic or manual shift of the underground ventilation system to HEPA filtration is assumed to not respond to mitigate a release for this scenario.

Estimated Frequency - The HAZOP Team qualitatively estimated the frequency of LOC in the Underground to be in the anticipated range ($10^{-1} \geq$ frequency $>10^{-2}$) for all the hazardous events.

The frequency of hazardous event 8-4 is not calculated because this event is prevented by passive design features[41].

- Design of the facility cask transfer car, facility cask, and waste hoist and shaft
- The facility cask is in a horizontal position and positioned with the greatest moment of inertia. It is held in place by trunions and supports to keep it from moving.
- Maximum speed of the facility cask transfer car is 30 ft (9.1 m) per minute.

Based on a quantitative evaluation using conservative assumptions documented in Appendix D (Figure D-2), the no mitigation annual occurrence frequency of the hazardous scenario 8-6, Drop of waste hoist to the bottom of the shaft, is beyond extremely unlikely. Risk evaluation guidelines are not identified for events with a frequency equal to or less than 10^{-6}/yr.

As shown in the event tree for this scenario, loss of power to the waste hoist motor is assumed to be the initiating event. WTSD-TME-063, Probability of a Catastrophic Hoist Accident at the Waste Isolation Pilot Plant,[42] identifies four dominant hoist accident scenarios, the most likely is power loss. Power failure may be due to loss of off-site power or coincident with the Design Basis Tornado (DBT) or earthquake (DBE). An evaluation of the off-site power loss frequency is conducted in Table D-3 of Appendix D. Comparing the frequency of the DBE (RH6) and DBT with the frequency of off-site power loss indicates that the most likely scenario is loss of off-site power.

Regardless of the initiating event, the hoist brake system functions to prevent the uncontrolled movement of the hoist, and prevents the resultant waste canister breach accident scenario. Due to the importance of this system, a fault tree analysis[42] on the waste hoist brake system was conducted: (1) to quantify the failure frequency on demand, (2) to verify system reliability, and (3) to identify system improvements or controls. The fault tree analysis of the current hoist configuration quantifies the frequency of failure as 1.3E-07/demand.

The no-mitigation frequency for the waste material release from the failure of the waste hoist is 9.05E-10/yr as shown in Figure D-2 of Appendix D.

An analysis of the frequency of hoist brake system failure has been performed by the Environmental Evaluation Group (EEG)[43]. The extensive uncertainty analysis performed in EEG-59, indicates that the mean frequency of 1.3E-07 corresponds to an 82 percent confidence level. At the 95 percent confidence level, the analysis indicates that the annual failure rate is 4.5E-07. The mean value of 1.3E-07 is used in the event tree in Figure D-2 for the failure probability of the brake system. The EEG analysis confirms, that the no-mitigation accident scenario frequency is beyond extremely unlikely (10^{-6}/yr $\geq$ frequency).

The input data and assumptions used for determining the failure probability of the brake system of the waste hoist are:

- Maintain configuration of the waste hoist on which fault tree was based (for details see WIPP/WID-96 -2178[40]).
- Maintenance program including post-maintenance functional testing - stroke testing is assumed for all valves following a maintenance operation
- Sensors and related components are regularly tested and calibrated. No attempt was made in this analysis to evaluate the possible consequences of faulty signals due to the miscalibration of the sensors
- Mission time for waste hoist is 1000 hours/yr (i.e, 7,000 round trips per yr) which includes transfer of RH and CH waste to the Underground
- Maximum test time for standby components is 24 hours
- Waste hoist is operated in automatic mode only when transferring RH waste because manual mode is not modeled in the fault tree analysis
- Assumed that neither inadvertent braking nor speed decrease would cause any safety concerns
- Assumed that neither inadvertent movement or speed increase would result in conditions beyond the design capabilities of the detection and protective features of the brake system
- Waste hoist system is subjected to a series of thorough "pre-operational check" test at the start of each eight hour shift. Operation of the waste hoist system does not begin until the tests are successfully completed. In the fault tree analysis this test interval is conservatively assumed to be three times greater or 24 hours.

- If the hoist system is to be operated more than one shift per day, or there is a change of operator, the hoist system will be removed from service and the same "pre-operational check" test will be performed.
- Based on the service life verification tests, the failure of the brake caliper unit is not considered
- Assumed that the system is structurally designed for thermal stresses/shocks
- Assumed that the ambient temperature is not below the freezing point of water

Source Term Development - No source term is developed for event 8-4 because this event is prevented by passive design features.

Event 8-6 postulates a drop of waste hoist to the bottom of the shaft during transfer of the RH waste canister to the Underground. This scenario could result in compromising the containment integrity of the waste canister and the facility cask.

Radiological Waste Canister Inventory (CI) - Based on the postulated scenario, the CI for this accident has been determined to be the inventory contained in one waste canister. As discussed in Section 5.2.1.1, it is assumed that the 72B waste canister contains the maximum radionuclide inventory of 80 PE-Ci for direct loaded waste and 240 PE-Ci for double contained waste. The waste canister is conservatively assumed to contain 95 percent noncombustible and five percent combustible material as discussed in Section 5.2.1.1.

Non-radiological Waste Canister Inventory (CI) - As discussed in Section 5.2.1.1, the non-radiological CI development process for events which involve a breach of a waste canister is simplified by assuming that 100 percent of the VOC headspace inventory is released instantaneously. VOCs selected for consideration for accidental releases are listed in Table 5.1-2. The weighted average of VOCs in the RH waste is assumed to be the same as in CH waste. The mass of VOC is based on the moles of gas present in the RH waste canister. A void space of 70 percent, same as in CH waste drums, is used for calculating moles of gas present in the RH waste canister.

Damage Ratio - It is assumed that the RH waste is directly loaded into the RH canister, and the canister is being transported to the underground within the facility cask when the accident occurs. As a result of the accident, the canister and facility cask will be most likely moderately damaged. The bounding damage ratio for a 55-gallon drum involved in the CH waste hoist accident is 0.25 from DOE/WIPP-95-2065, WIPP Contact Handled (CH) Waste Safety Analysis Report.[6] When comparing the structural integrity of the RH canister to that of the CH drum, the RH canister is more robust, therefore a DR of 0.25 is conservatively assigned for this RH accident scenario.

DOE/WIPP-95-2065[6] "overpack" scenarios assume that 55-gal drums are overpacked within a standard waste box (SWB). The product of the damage ratios for the 55-gal drum overpacked within a SWB, and the SWB, is the overall DR for the "overpack" involved in drop scenarios. This method is also applied to a 55-gal drum within an RH canister.

The RH canister will hold three 55-gal drums each containing RH waste. However, for conservatism it is assumed that all the waste is in the bottom drum, and that drum is impacted by the accident conditions and releases 10 percent of its contents. Therefore, assuming a conservative DR of 0.1 for drums within the RH canister, a conservative RH-canister overpack DR would be 0.1 x 0.25 = 0.025 for the Hoist Drop scenario.

Airborne Release Fraction and Respirable Fraction - As discussed in Section 5.2.1.1, the ARF for contaminated combustible materials which are subjected to impact and breach of the waste canister is 0.001. This value represents a bounding ARF for packaged material in a canister which fails due to impact (DOE-HDBK-3010-94, subsection 5.2.3.2).[4] The bounding RF is 0.1 (DOE-HDBK-3010-94, subsection 5.2.3.2).[4]

The ARF for contaminated noncombustible materials which are subjected to impact and breach of the waste canister for solids that do not undergo brittle fracture is 0.001. This value represents a bounding ARF for packaged material in a canister which fails due to impact (DOE-HDBK-3010-94, subsection 5.3.3.2.2).[4] The bounding RF is 1.0 (DOE-HDBK-3010-94, subsection 5.2.3.2).[4]

Leakpath Factor - Due to the accident scenario conditions and potential damage to both the RH canister and the facility cask, a conservative LPF from the facility cask to the underground of 1.0 is assigned.

The amount of material removed from the air due to the HEPA filters is predicted based on DF. DF have been predicted for accident conditions in the handbook ERDA 76-21.[14] Based ERDA 76-21, the total DF used in this analysis for both stages of filtration is 1.0E+06. The LPF is 1.0E-06 for the mitigated case and 1.0 for the unmitigated case.

Estimated noninvolved worker and MEI Consequences and Comparison to Risk Evaluation Guidelines - Based on the values for the source term variables as presented above, the worst-case, unmitigated MEI and noninvolved worker consequences (see Appendix E, Tables E-4, E-5, and E-6) of the LOC in the Underground (Waste Hoist Drop) (RH4-A) are well within the radiological and non-radiological risk evaluation guidelines for the extremely unlikely range.

Assessment of Immediate Worker Consequences- No current risk evaluation guidelines exist for the assessment of accident consequences to immediate workers. Therefore, in the absence of guidelines, and for conservatism, the noninvolved worker radiological guidelines for the extremely unlikely range are used as a reference point for the assessment of consequences to immediate workers and the evaluation of the adequacy of the WIPP defense-in-depth features. The worst-case consequences to the immediate worker from RH4A (Tables E-13 and E-16) exceed the risk evaluation guidelines. However, no specific additional worker protection engineering or administrative controls beyond those already qualitatively identified as providing defense-in-depth for the immediate worker, are needed based on the discussion provided in Section 5.2.4.2.

Safety Structures, Systems, and Components - The brake system on the waste hoist has been designated as Safety Significant. The following input data and assumptions are used in the accident analysis:

- Design of the facility cask transfer car, facility cask, and waste hoist and shaft
- The facility cask is in a horizontal position and positioned with the greatest moment of inertia. It is held in place by trunions and supports to keep it from moving.
- Maximum speed of the facility cask transfer car is 30 ft (9.1 m) per minute
- Maintain configuration of the waste hoist on which fault tree was based (for details see WIPP/WID-96 -2178[40])
- Maintenance program including post-maintenance functional testing- stroke testing is assumed for all valves following a maintenance operation

- Mission time for waste hoist is 1000 hours/yr (i.e, 7,000 round trips per yr) which includes transfers of RH and CH waste to the Underground
- Maximum test time for standby components is 24 hours
- Waste hoist is operated in automatic mode only when transferring RH waste because manual mode is not modeled in the fault tree analysis
- Waste hoist system is subjected to a series of thorough "pre-operational check" test at the start of each eight hour shift. Operation of the waste hoist system does not begin until the tests are successfully completed. In the fault tree analysis this test interval is conservatively assumed to be three times greater or 24 hours.
- If the hoist system is to be operated more than one shift per day, or there is a change of operator, the hoist system will be removed from service and the same "pre-operational check" test will be performed

The defense-in-depth SSCs which are applicable to this scenario, per the criteria provided in Chapter 3, Section 3.1.3 are assigned as follows:

- Vented DOT Type A (or equivalent) waste canister - Primary confinement
- Underground Ventilation Exhaust System - Secondary confinement
- Radiation Monitoring System (active waste disposal room exit alpha CAM for underground shift to filtration) - Secondary confinement
- Underground Ventilation Exhaust HEPA Filters - Secondary confinement
- Central Monitoring System (for actuation of underground shift to filtration only) - Secondary confinement
- Design of facility cask - Prevents/minimizes releases from the waste canister

The defense-in-depth ACs which are applicable to this scenario, per the criteria in Chapter 3, Section 3.1.3 are assigned as follows:

- The door to the waste hoist is not opened until the conveyance is locked in position and the pivot rails are in place - Prevents the drop of the facility cask into the shaft

Section 5.2.4.1, Evaluation of the Design Basis, discusses in greater detail: (1) the evaluation of safety SSCs, and (2) the applicability of functional and performance requirements (system evaluation) and controls (TSRs). Detailed design descriptions for the above defense-in-depth SSCs may be found in Chapter 4 and the applicable SDDs.

Due to the importance of WIPP programs relating to configuration and document control, quality assurance, conduct of operations, preventative maintenance and inspection, waste handling procedures and training, the WIPP RH WAC, and the WIPP Emergency Management Program[36] and associated procedures, in the WIPP defense-in-depth strategy for this accident, TSR ACs are derived in Chapter 6 and required in the WIPP TSR Document.

5.2.3.5 RH4-B Loss of Confinement in the Underground (Waste Movement)

Scenario Description - The HAZOP[28] postulated a LOC of the waste material in the Underground. The HAZOP[28] postulated four hazardous waste movement events (9-5, 10-1, 10-5, and 10-6) that could result in a LOC of the waste material in the Underground. The LOC event could cause a significant release of radioactivity.

Hazardous event 9-5 postulates a drop of the facility cask by a forklift during transfer of facility cask in the Underground. The cause of this event is human error, forklift collision, equipment failure forklift hydraulic system, or structural failure of fork tines. The potential consequences of this event are: breach of a waste canister, significant radiological exposure to personnel, major release of radioactive materials, considerable impact offsite, and worker fatality. The potential breach of a waste canister could cause a significant release of radioactivity to the environment.

Hazardous event 10-1 postulates a loss of control where the forklift drops the facility cask onto the HERE. The cause of this event is human error, or equipment failure. The potential consequences of this event are: breach of a waste canister, major damage to the HERE, significant radiological exposure to personnel, major release of radioactive materials, and considerable impact offsite. The potential breach of a waste canister could cause a significant release of radioactivity to the environment.

Hazardous event 10-5 postulates a closure of a facility cask shield valve on a waste canister (mispositioned shield valve or movement sooner than desired) while it is being emplaced. The causes of this event are control loop failure and mechanical failure on the emplacement equipment. The potential consequences of this event are: damage or breach of a waste canister, release of radioactive material, direct radiological exposure, and adverse impact offsite. The potential breach of a waste canister could cause a significant release of radioactivity to the environment.

Hazardous event 10-6 postulates misalignment of waste canister as it is moved into the borehole. The causes of this event are: human error and equipment failure - HERE settles and results in misalignment or level indicator malfunctions. The potential consequences of this event are: damage or breach of a waste canister, damage to HERE, release of radioactive material, direct radiological exposure, and adverse impact offsite. The potential breach of a waste canister could cause a significant release of radioactivity to the environment.

Preventive and Mitigative Features - General preventive and mitigative measures identified in the HAZOP for this specific scenario are listed in Table 5.1-10. For the no mitigation case, automatic or manual shift of the underground ventilation system to HEPA filteration is assumed to not respond to mitigate a release for this scenario.

Estimated Frequency - The HAZOP Team qualitatively estimated the frequency of LOC in the Underground to be in the anticipated range ($10^{-1} \geq$ frequency $>10^{-2}$) for all the hazardous events.

The hazardous event 10-5, closure of shield valve on waste canister, is prevented by the following passive design feature:

- Design of the shield valve motor (torque limiter) is such that an inadvertent closure of shield valve will not affect the containment integrity of the waste canister during its emplacement in the borehole

Hazardous event 10-6, misalignment of waste canister as it is moved into the borehole, is prevented by the following passive design feature:

- Design of hydraulic system will be such that the containment integrity of a misaligned waste canister is not affected during its emplacement in the borehole

The frequency of hazardous events 10-5, and 10-6 is not calculated because these events are prevented by the passive design features.

Both hazardous scenarios, 9-5, drop of the facility cask by a forklift, and 10-1, loss of control causes a drop of the facility cask onto the HERE, are evaluated in a single event tree. As shown in the event tree analysis for these scenarios in Appendix D, Table D-4, the quantitative evaluation gave an annual occurrence frequency in the unlikely range (10^{-4}/yr < frequency $\leq 10^{-2}$/yr) for the case with no-mitigation. The event tree assumes the following:

- Throughput of waste canisters is 208/year which translates to 208 forklift operations per year.
- The Underground panel room floor will be leveled prior to storage operations
- A spotter is present whenever forklift is used to transfer waste canister in the Underground
- Maximum time to transfer one waste canister to the HERE equipment in the Underground is approximately 4 hours

Source Term Development - The following are two different scenarios that could occur during the transfer of waste canister by a forklift in the Underground.

- Drop of the facility cask by a forklift in the Underground (event 9-5) and
- Loss of control causes a drop of the facility cask onto the HERE (event 10-1)

Both these drop scenarios could result in compromising the containment integrity of the waste canister because the bottom of the facility cask is >4 ft (1.2 m) from the floor of the Underground.

Radiological Waste Canister Inventory (CI) - Based on the postulated scenario, the CI for this accident has been determined to be the inventory contained in one waste canister. It is assumed that the waste canister contains the maximum radionuclide inventory of 80 PE-Ci (direct loaded) and 240 PE-Ci (double confined). The waste canister is conservatively assumed to contain 95 percent noncombustible and five percent combustible material as discussed in Section 5.2.1.1.

Non-radiological Waste Canister Inventory (CI) - The non-radiological CI development process for events which involve a breach of a waste canister is simplified by assuming that 100 percent of the VOC headspace inventory is released instantaneously. VOCs selected for consideration for accidental releases are listed in Table 5.1-2. The weighted average of VOCs in the RH waste is assumed to be the same as in CH waste. The mass of VOCs is based on the moles of gas present in the RH waste canister. A void space of 70 percent, same as in CH waste drums, is used for calculating moles of gas present in the RH waste canister.

Damage Ratio - As discussed in Section 5.2.1.1, for drops of waste canisters from heights > 4 ft, and $\leq$ 22 ft (6.7 m) (4 ft [1.2 m]<h $\leq$ 22 ft [6.7 m]), it is conservatively assumed that the DR for facility cask containing a Type A (or equivalent) waste canister in this type of accident is 0.01 (DR=0.01) for direct loaded waste and 0.001 (DR =0.001) for double confined waste.

Airborne Release Fraction and Respirable Fraction - As discussed in Section 5.2.1.1, the ARF for contaminated combustible materials which are subjected to impact and breach of the waste canister is 0.001. This value represents a bounding ARF for packaged material in a canister which fails due to impact (DOE-HDBK-3010-94, subsection 5.2.3.2).[5] The bounding RF is 0.1 (DOE-HDBK-3010-94, subsection 5.2.3.2).[4]

The ARF for contaminated noncombustible materials which are subjected to impact and breach of the waste canister for solids that do not undergo brittle fracture is 0.001. This value represents a bounding ARF for packaged material in a canister which fails due to impact (DOE-HDBK-3010-94, subsection 5.3.3.2.2).[4] The bounding RF is 1.0 (DOE-HDBK-3010-94, subsection 5.2.3.2).[4]

Leakpath Factor - Based on the scenario description, it is not expected that a waste canister drop in the Underground will also disable the underground ventilation or HEPA filtration systems. Shift of the underground ventilation system may occur manually or automatically as discussed in detail in Section 4.4.2.3. However, it is assumed that an automatic shift to filtration will not respond to mitigate a release for this scenario. For the mitigated case, it is assumed that the CMR operator will be notified or be aware of the accident and actuate the shift to filtration. Credit is <u>not</u> taken for the natural attenuation provided by the discharge path.

Estimated non-involved worker and MEI Consequences and Comparison to Risk Evaluation Guidelines- Based on the values for the source term variables as presented above, the worst-case, no-mitigation MEI and noninvolved worker consequences (see Appendix E, Tables E-7, E-8, and E-9) of the LOC in the Underground (RH4-B) are well within the radiological and non-radiological risk evaluation guidelines for the extremely unlikely range.

Assessment of Immediate Worker Consequences- No current risk evaluation guidelines exist for the assessment of <u>accident</u> consequences to immediate workers. Therefore, in the absence of guidelines, and for conservatism, the noninvolved worker radiological guidelines are used as a reference point for the assessment of consequences to immediate workers and the evaluation of the adequacy of the WIPP defense-in-depth features. The worst-case consequences to the immediate worker from RH4-B (Table E-14 and E-17) are well within the risk evaluation guidelines. Therefore, no specific additional worker protection engineering or administrative controls beyond those already qualitatively identified as providing defense-in-depth for the immediate worker, are needed based on the quantitative consequence assessment results.

Safety Structures, Systems, and Components - Based on the estimated worst-case no-mitigation MEI and noninvolved worker consequences and comparison to the risk evaluation guidelines, Safety Class or Safety significant SSCs are not required. The following input data and assumptions are used in the accident analysis:

- Design of motor on the shield valve will be such that an inadvertent closure of shield valve will not affect the containment integrity of the waste canister during its emplacement in the borehole
- Design of hydraulic system will be such that the containment integrity of a misaligned waste canister is not affected during its emplacement in the borehole
- Throughput of waste canisters is 208/year which translates to 208 forklift operations per year.
- Underground panel room floor will be leveled prior to storage operations
- A spotter is present whenever forklift is used to transfer waste canister in the Underground

- Maximum time to transfer one waste canister to the emplacement equipment in the Underground is approximately 4 hours

The defense-in-depth SSCs which are applicable to this scenario, per the criteria in Chapter 3, Section 3.1.3 are assigned as follows:

- Vented DOT Type A (or equivalent) waste canister - primary confinement
- Underground Ventilation Exhaust System - secondary confinement
- Radiation Monitoring System (active waste disposal room exit alpha CAM for underground shift to filtration) - secondary confinement
- Underground Ventilation Exhaust HEPA Filters - secondary confinement
- Central Monitoring System (for actuation of underground shift to filtration only) - secondary confinement
- Forklift and Attachments - Designed to minimize waste canister drops
- Design of facility cask - Prevents/minimizes releases from the waste canister

The defense-in-depth ACs which are applicable to this scenario, per the criteria in Chapter 3, Section 3.1.3 are assigned as follows:

- No other vehicle movement is allowed during RH waste movement in the Underground.

Section 5.2.4.1, Evaluation of the Design Basis, discusses in greater detail: (1) the evaluation of safety SSCs, and (2) the applicability of functional and performance requirements (system evaluation) and controls (TSRs). Detailed design descriptions for the above defense-in-depth SSCs may be found in the applicable SDDs as referenced in Chapter 4.

Due to the importance of WIPP programs relating to configuration and document control, quality assurance, conduct of operations, preventative maintenance and inspection, waste handling procedures and training, the WIPP RH WAC, and the WIPP Emergency Management Program[36] and associated procedures, in the WIPP defense-in-depth strategy for this accident, TSR ACs are derived in Chapter 6 and required in the WIPP TSR Document.

5.2.3.6 RH5 Fire Followed by Explosion in the Underground

Scenario Description - The HAZOP[28] postulated a fire followed by explosion in the Underground. The HAZOP[28] postulated two hazardous events (9-8 and 10-3) that could result in a fire followed by explosion in the Underground. The fire and subsequent explosion could cause a significant release of radioactivity.

Hazardous event 9-8 postulated a diesel fuel fire followed by explosion on forklift during the transfer of facility cask to disposal room. The forklift usually has about 20 gals (75.7 L) of diesel fuel. The cause of this event is a diesel fuel leak. An ignition source could ignite the fuel and cause a fire and then a subsequent explosion. The fire and subsequent explosion could potentially damage the facility cask and waste canister and cause a breach of the waste canister because neither the facility cask or the waste canister are qualified for a fire or explosion. The thermal and explosive stress on the waste canister could cause a significant release of radioactivity. The immediate worker(s) could also receive a significant direct radiological exposure from the breached waste canister.

Hazardous event 10-3 postulated a hydraulic oil fire on the HERE during the emplacement of waste canister in borehole. The HERE usually has about 40 gal (151.4 L) of hydraulic oil[29]. The cause of this event is a hydraulic oil leak. An ignition source could ignite this fuel and may cause a fire and maybe a subsequent explosion. According to its MSDS, the hydraulic oil is slightly flammable (NFPA rating of 1) and there is no explosion hazard[30]. On the basis of following conditions, it is not likely that a hydraulic oil fire will start:

- The leaked hydraulic oil will form a pool under and around HERE because there is no catch pan to collect any potential leaks. The leaked hydraulic oil will be absorbed by the salt and there could be a small layer of hydraulic oil on the salt surface.
- There are no known ignition sources that could ignite hydraulic oil.

Even if the fire is started, there will be no release of radioactive material as shown in accident RH1, Fire in the Underground.

Preventive and Mitigative Features - General preventive and mitigative measures identified in the HAZOP for this specific scenario are listed in Table 5.1-10.

Estimated Frequency - The HAZOP Team qualitatively estimated the frequency of occurrence of a fire followed by an explosion in a waste canister in the Underground facility to be in the anticipated range ($10^{-1} \geq$ frequency$>10^{-2}$) for both hazardous events. For accident RH1, the overall frequency of breach of waste canister due to fire from forklift operations in the Underground is beyond extremely unlikely (10^{-6}/yr $\geq$ frequency). Therefore, the frequency of an explosion after fire would be lower and would still fall under the beyond extremely unlikely bin. Risk evaluation guidelines are not identified for an event with a frequency $\leq 10^{-6}$/yr. The frequency for event 10-3 was not calculated because there is no explosion hazard from the hydraulic oil.[30]

Source Term Development - The frequency of this accident is Beyond Extremely Unlikely (BEU) (10^{-6}/yr $\geq$ frequency). This event is analyzed in this section and discussed further in the Beyond Design Basis Accident (BDBA) section.

Radiological Waste Canister Inventory (CI) - Based on the postulated scenario, the CI for this accident has been determined to be the inventory contained in one waste canister. As discussed in Section 5.2.1.1, it is assumed that the waste canister contains the maximum radionuclide inventory of 80 PE-Ci for direct loaded waste and 240 PE-Ci for double confined waste. The waste canister is conservatively assumed to contain 95 percent noncombustible and five percent combustible material as discussed in Section 5.2.1.1.

Non-radiological Waste Canister Inventory (CI) - As discussed in Section 5.2.1.1, the non-radiological CI development process for events which involve a breach of a waste canister is simplified by assuming that 100 percent of the VOC headspace inventory is released instantaneously. VOCs selected for consideration for accidental releases are listed in Table 5.1-2. The weighted average of VOCs in the RH waste is assumed to be the same as in CH waste. The mass of VOCs is based on the moles of gas present in the RH waste canister. A void space of 70 percent, same as in CH waste drums, is used for calculating moles of gas present in the RH waste canister.

Damage Ratio - Based on the design of the 41 ton forklift, the canister inside the facility cask is located approximately 15 feet from the fuel tank where the explosion occurs. It is conservatively assumed, to encompass the uncertainty in the application of test data and the variation in waste forms, that the DR for facility cask containing a Type A (or equivalent) waste canister in this class of accident is 0.01 (DR=0.01) for direct loaded waste and 0.001 (DR =0.001) for double confined waste.

Airborne Release Fraction and Respirable Fraction - As discussed in Section 5.2.1.1, the ARF for contaminated combustible materials which are subjected to impact from the explosion and breach of the waste canister is 0.001. This value represents a bounding ARF for packaged material in a canister which fails due to impact from the explosion (DOE-HDBK-3010-94, subsection 5.2.3.2).[5] The bounding RF is 0.1 (DOE-HDBK-3010-94, subsection 5.2.3.2).[4]

The ARF for contaminated noncombustible materials which are subjected to impact from the explosion and breach of the waste canister for solids that do not undergo brittle fracture is 0.001. This value represents a bounding ARF for packaged material in a canister which fails due to impact from the explosion (DOE-HDBK-3010-94, subsection 5.3.3.2.2).[4] The bounding RF is 1.0 (DOE-HDBK-3010-94, subsection 5.2.3.2).[4]

Leakpath Factor - Based on the scenario description, it is not expected that a fire followed by an explosion in the Underground will also disable the underground ventilation or HEPA filtration systems. Shift of the underground ventilation system may occur manually or automatically as discussed in detail in Section 4.4.2.3. However, it is assumed that an automatic shift to filtration will not respond to mitigate a release for this scenario. For the mitigated case, it is assumed that the CMR operator will be notified or be aware of the accident and actuate the shift to filtration. Credit is not taken for the natural attenuation provided by the discharge path.

Estimated non-involved worker and MEI Consequences and Comparison to Risk Evaluation Guidelines- Based on the values for the source term variables as presented above, the worst-case, no-mitigation MEI and noninvolved worker consequences (see Appendix E, Tables E-10, E-11, and E-12) of the Fire followed by an Explosion in the Underground (RH5) are within the radiological and non-radiological risk evaluation guidelines for the extremely unlikely range.

Assessment of Immediate Worker Consequences- No current risk evaluation guidelines exist for the assessment of accident consequences to immediate workers. Therefore, in the absence of guidelines, and for conservatism, the noninvolved worker radiological guidelines are used as a reference point for the assessment of consequences to immediate workers and the evaluation of the adequacy of the WIPP defense-in-depth features. The worst-case consequences to the immediate worker from RH5 (Table E-15) are well within the risk evaluation guidelines. Therefore, no specific additional worker protection engineering or administrative controls beyond those already qualitatively identified as providing defense-in-depth for the immediate worker, are needed based on the quantitative consequence assessment results.

Safety Structures, Systems, and Components - Based on the frequency of this accident, Safety Class or Safety significant SSCs are not required. The following input data and assumptions are used in the frequency analysis:

- Throughput of waste canisters is 208/year which translates to 208 forklift operations per year.
- There is not another facility cask containing a RH waste canister or any CH waste in the path of the forklift transporting a filled facility cask to the disposal room.
- RH waste canisters are vented
- A spotter is present when the RH waste canister is transported by the forklift in the Underground.
- Maximum volume of hydraulic oil in the HERE is $\leq$ 40 gal (151.4 L).

The defense-in-depth SSCs which are applicable to this scenario, per the criteria in Chapter 3, Section 3.1.3 are assigned as follows:

- Vented DOT Type A (or equivalent) RH Canister - primary confinement
- Underground Ventilation System - secondary confinement
- Design of Fuel and Hydraulic Oil Tank - Designed to minimize leaks

Section 5.2.4.1, Evaluation of the Design Basis, discusses in greater detail: (1) the evaluation of safety SSCs and (2) the applicability of functional and performance requirements (system evaluation) and controls (TSRs). Detailed design descriptions for the above defense-in-depth SSCs may be found in the applicable SDDs as referenced in Chapter 4.

Due to the importance of the WIPP Emergency Management Program,[36] TSR ACs are derived in Chapter 6 and required in the WIPP TSR document.

5.2.3.7 RH6 Seismic Event

Scenario Description - The possibility of a seismic event has been identified as part of the HAZOP [28] performed for the RH TRU Waste Handling system. This scenario represents a natural phenomena induced accident which may involve the potential breach of waste canisters.

The hazardous event 13-1 postulates a design basis earthquake (DBE). As discussed in Chapters 2 and 3 of this SAR, the DBE is the most severe credible earthquake expected to occur at the WIPP Site. The DBE is based on a 1,000-year return interval established through a site specific study. The maximum ground acceleration for the DBE is 0.1 g in both the horizontal and vertical directions, with ten maximum stress cycles. The potential consequences of this event are: major disruption of facility operations, damage or breach of a waste canister(s), loss of site utilities, release of radioactive materials, radiological impact offsite, fire, explosion, and worker injury and/or fatality. The potential breach of a waste canister could cause a significant release of radioactivity to the environment.

There is a possibility of a subsequent fire after a DBE in the above ground facilities at WIPP. An analysis done at Savannah River Site shows that the frequency of a fire after an unlikely seismic event is extremely unlikely [44]. It is assumed that the frequency of a fire after a DBE at WIPP would also be extremely unlikely (10^{-4}/yr $\geq$ frequency $>10^{-6}$/yr). As shown in accident RH2, the maximum temperature of the waste canister will be ≤ 500 °F (260°C) from a potential hydraulic oil fire in the WHB. Thus there will be no release of waste material from the waste canister after a hydraulic oil fire. The other potential fires after a DBE are evaluated in *Source Term Development.*

Mine experience and studies on earthquake damage to underground facilities show that tunnels, mines, wells, etc., are not damaged for sites having peak accelerations at the surface below 0.2 g [45]. Therefore, underground structures and components are not subject to DBE[6]. There would be no release of RH waste material from the underground facilities.

It is postulated that as a result of the DBE, internal events within the WHB may cause the loss of primary containment (e.g. process/equipment disruption resulting in waste canister drops/falls and breaches) and release airborne radiological and/or non-radiological hazardous materials. The above ground WHB RH waste handling process was reviewed to determine the process step (1) most vulnerable to the DBE, and (2) bounding in terms of potential to release airborne hazardous materials.

Two process steps were identified: (1) the loading of a waste canister into the facility cask and movement of facility cask, containing a waste canister, to the Conveyance Loading Room, and (2) 72B cask in the Transfer Cell in the process of being unloaded, are considered as the most vulnerable to DBE movement.

Design Class II DBE SSCs, including the WHB structure and structural components, and tornado doors are designed to withstand a DBE free-field horizontal and vertical ground acceleration of 0.1 g, based on a 1,000-year recurrence period, <u>and retain their design function</u>[6]. Additionally, the main lateral force resisting members of the Support Building and Building 412 are DBE designed to protect the WHB from their structural failure. Therefore, there would be no release from the 72B cask or facility cask as they are being processed in the WHB.

The original design for WIPP used the 1982 Uniform Building Code and predated both DOE 6430.1A and UCRL-15910[46]. An updated assessment of the DBE was performed in 1990 by Bechtel.[47] The assessment showed that the design classifications shown in the original design for WIPP either met or exceeded the newer standards for DBE for nonreactor facilities.

With regard to coincident power loss during a DBE, off-site power loss is analyzed in the initiating event development for the RH3, LOC in the WHB, and RH4-A, LOC in the Underground (waste hoist failure), accident scenarios. The RH cranes and waste hoist design provides for fail safe condition during loss of power (brake set during loss of power). Also, since the waste hoist system (headframe, waste shaft, and shaft furnishings) will withstand the DBE, no release scenarios are postulated involving failure of the hoist as a result of a DBE initiating event. The frequency of coincident DBE and/or DBE power loss, <u>and</u> failure of the waste hoist brakes is beyond extremely unlikely. The analysis in RH3 and RH4-A consider, in quantification of the event frequencies, the more likely scenario of loss of normal off-site power, as opposed to resulting from a less likely DBE. Regardless of initiating event frequency, the consequences of RH3 and RH4-A, if off-site power loss and failure of the brake systems were to occur, are analyzed in each respective accident scenario evaluation in this section.

Preventive and Mitigative Features - General preventive and mitigative measures identified in the HAZOP for this specific scenario are listed in Table 5.1-10. These measures should be reviewed to comprehend the amount of features that are in place that either prevent and/or mitigate against this accident.

Estimated Frequency - The DBE is based on a 1,000-year return interval. The frequency of the DBE is 10^{-3}/yr and the frequency bin is "unlikely" (10^{-2}/yr $\geq$ frequency $>10^{-4}$/yr).

Source Term Development - The waste canister will maintain its containment function because the following systems will retain their design function during and after a DBE:

- Grapple hoist is designed such that it would not drop or affect the containment integrity of the waste canister when transferring a waste canister from the 72B cask into the facility cask during and after a DBE.
- Shuttle car in the Transfer Cell is designed such that it would not drop or affect the containment integrity of the waste canister during and after a DBE
- Equipment in the Transfer Cell is designed such that it would not affect the containment integrity of the waste canister during and after a DBE.

- Fires starting in the Support Building, the WHB, or Building 412 has the potential to destroy the entire structure. This potential fire was analyzed and the frequency was found to be beyond extremely unlikely in the existing FHA[48]. The design of the RH waste handling operation is such that fires starting in the WHB will not have the fuel load to spread to other areas. This lack of potential is due to low combustible loading, the favorable arrangement of combustible materials, relatively few ignition sources, and the large open space with high ceiling that characterizes most of the work areas.

No hazardous material is postulated to be released during the DBE because of the design features described above, therefore, no source term is developed.

Estimated Consequences and Comparison to Risk Evaluation Guidelines - No hazardous material is postulated to be released during the DBE, therefore, no consequence analysis is developed.

Safety Structures, Systems, and Components - No hazardous material is postulated to be released during the DBE, therefore no Safety Class or Safety Significant SSCs are not required. The following input data and assumptions are used in the analysis:

- Grapple hoist is designed such that it would not drop or affect the containment integrity of the waste canister when transferring a waste canister from the 72B cask into the facility cask during and after a DBE.
- Shuttle car in the Transfer Cell is designed such that it would not drop or affect the containment integrity of the waste canister during and after a DBE
- Equipment in the Transfer Cell is designed such that it would not affect the containment integrity of the waste canister during and after a DBE.

The defense-in-depth SSCs which are applicable to this scenario, per the criteria provided in Chapter 3, Section 3.1.3 are assigned as follows:

- Vented DOT Type A (or equivalent) waste container - primary confinement
- Design of facility cask - Prevents/minimizes releases from the waste canister
- Design of 72B cask - Prevents/minimizes releases from the waste containers (drums/canis)

Section 5.2.4.1, Evaluation of the Design Basis, discusses in greater detail: (1) the evaluation of safety SSCs, and (2) the applicability of functional and performance requirements (system evaluation) and controls (TSRs). Detailed design descriptions for the above defense-in-depth SSCs may be found in the applicable SDDs as referenced in Chapter 4.

As shown in Chapter 6, based on the criteria for assigning Technical Safety Requirement (TSR) Limiting Conditions for Operation (LCOs), these equipment are not assigned TSR LCOs. However, due to the importance of DBE qualification, and programs relating to configuration and document control, quality assurance, preventative maintenance and inspection, the WIPP RH WAC, and the WIPP Emergency Management in the WIPP defense-in-depth strategy for this accident, TSR ACs are derived in Chapter 6 and required in the WIPP TSR Document.

5.2.3.8 RH7 Tornado Event

The RH waste handling processes at WIPP are examined for the need to protect against high wind, tornado, and wind blown missiles. Underground facilities are inherently protected against these phenomenon, and as such, the examination deals only with surface facilities. Areas of concern for the release of radiological and non-radiological hazardous materials associated with RH TRU waste are: (1) road cask parking and unloading areas; (2) RH waste handling areas within the WHB, the waste hoist, WHB, and underground ventilation systems. These are described as follows:

- The 72B cask is designed to withstand the effects of high wind, tornado, tornado driven missiles, and overturning without the release of waste contents as part of the RH-TRU 72-B road cask safety analysis report[49].
- The WHB (including the cranes and grapple hoist used for RH waste handling) and waste hoist are protected by the WHB structure, and tornado doors. The structure and doors, passively withstand the winds, pressure change, and missile forces to ensure that the waste and waste hoist are not subjected to unacceptable forces.
- All WHB tornado doors are required to be closed when RH waste is present in the WHB.
- The WHB exhaust system and HEPA filters are contained within the WHB and are protected from wind forces and missiles by the tornado hardened features of the building structure and the tornado hardened closures (doors). The ventilation system is not required to remain operating during and after the tornado, but rather is protected against dispersal of minor contamination on HEPA filters. No tornado coincident need for confinement active ventilation is postulated due to the extremely low tornado frequency and the absence of common cause events since all crane and hoisting mechanisms are protected (with braking systems that <u>actuate</u> upon loss of power) from accident conditions due to loss of power.

Scenario Description - The possibility of a tornado event has been identified as part of the HAZOP[28] performed for the RH TRU Waste Handling system. Hazardous event 13-2 postulates a design basis tornado (DBT). The potential consequences of this event are: breach of waste canister, personnel injury or fatality, major release of radioactive materials, considerable impact onsite and offsite, and loss of site utilities.

As discussed in Chapters 2 and 3, the DBT is the most severe credible tornado that could occur at the WIPP Site. The DBT used for the WIPP has a maximum wind speed of 183 mi (284.5 km) per hour including effects of suction vortices, a translational velocity of 41 mi (65.9 km) per hour, a tangential velocity of 124 mi (200 km) per hour, a 325 ft (99 m) radius of maximum wind, pressure drop of 0.5 lb/in^2 (351.5 kg/m^2), and rate of pressure drop of 0.09 lb/in^2 (63.3 kg/m^2) per second, with a mean recurrence interval of 1,000,000 years.

Design Class II DBT SSCs (see Table 4.1-1) are designed to withstand winds generated by this tornado (183 mi [284.5 km] per hour), based on a 1,000,000-year recurrence period, <u>and retain their safety function</u>. The WHB structure and structural components (including the cranes and grapple hoist used for RH waste handling), including tornado doors are designed to withstand the DBT.

No credible internal events within the WHB can be postulated to cause the loss of primary confinement (e.g. process/equipment disruption resulting in waste canister drops/falls and breaches) and release airborne radiological or non-radiological hazardous materials as a result of the DBT. With regard to coincident power loss during a DBT, off-site power loss is analyzed in RH3 and RH4-A accident scenarios. The cranes and waste hoist design provides for fail safe condition during loss of power (brake set during loss of power). The frequency of coincident DBT caused power loss and failure of the cranes or waste hoist brakes is beyond extremely unlikely (10^{-6}/yr $\geq$ frequency). The analyses in RH3 and RH4-A consider the more likely scenario of loss of normal off-site power, as opposed to resulting from a less likely DBT. The consequences of RH3 and RH4-A, if off-site power loss and failure of the brake systems were to occur, are analyzed in each respective accident scenario evaluation.

With regard to the effects of missiles generated by the DBT, the WIPP is designed on a single failure basis. It is considered incredible that two or more failure events (breach of the WHB and breach of waste canister by a DBT missile which results in a release of significant quantities of radionuclides that require confinement) can occur simultaneously, therefore, the effects of missiles are not evaluated.

Table 4.1-1, identifies those Design Class II and IIIA DBT SSCs, Table 3.1-2 identifies the applicable design code requirements, and Section 3.2 identifies the applicable DBT structural design criteria for WIPP DBT SSCs. Detailed design information may be found in the respective SDD.

Design Class II and IIIA SSCs from Table 4.1-1 applicable to the DBT aboveground are the:

- WHB structure and structural components (including the cranes and grapple hoist used for RH waste handling) including tornado doors - Design Class II (provides physical confinement)

Additionally, the auxiliary Air Intake shaft and tunnel (Bldg. 465) is DBT designed, and the main lateral force resisting members of the Support Building and Building 412 are DBT designed to protect the WHB from their structural failure.

As shown in Table 3.1-2, Design Class II, and IIIA structures and supports necessary for the confinement of radioactivity are DBT designed. The function provided is to prevent tornado forces or missiles from causing failure of the primary confinement boundaries (waste canister). Therefore, no releases of hazardous materials are postulated as a result of the WIPP DBT designed mitigative/preventative SSCs.

Preventive and Mitigative Features - General preventive and mitigative measures identified in the HAZOP for this specific scenario are listed in Table 5.1-10.

Estimated Frequency - The DBT is the most severe credible tornado (183 mi [284.5 km] per hour wind) that could occur at the WIPP site, based on a 1,000,000-year recurrence period. Therefore, the frequency of the DBT event is 10^{-6}/yr and the frequency bin is "extremely unlikely" (10^{-4}/yr $\geq$ f >10^{-6}/yr).

The DBT was developed by a site specific study SMRP No. 155, "A Site-Specific Study of Wind and Tornado Probabilities at the WIPP Site in Southeast New Mexico," Department of Geophysical Sciences, T. Fujita, University of Chicago, February 1978 and its Supplement of August 1978. [50]

Source Term Development - No hazardous material is postulated to be released as a result of the DBT, therefore, the source term development is not required.

Estimated Consequences and Comparison to Risk Evaluation Guidelines - No hazardous material is postulated to be released as a result of the DBT, therefore, consequence analysis is not required.

Assessment of Immediate Worker Consequences- As discussed in Section 5.2.1.2, this scenario is not evaluated for immediate worker consequences.

Safety Structures, Systems, and Components - No hazardous material is postulated to be released during the DBT; therefore, Safety Class or Safety Significant SSCs are not required. The following input data and assumptions are used in the analysis:

- The 72B cask is designed to withstand the effects of high wind, tornado, tornado driven missiles, and overturning without the release of waste contents as part of the RH-TRU 72-B road cask safety analysis report[49].
- The WHB (including the cranes and grapple hoist used for RH waste handling) and waste hoist are protected by the WHB structure, and the tornado doors.

The defense-in-depth SSCs which are applicable to this scenario, per the criteria provided in Chapter 3, Section 3.1.3 are assigned as follows:

- WHB structure (includes structure and structural components which includes the cranes and grapple hoist used for RH waste handling) designed to prevent failure during a DBT resulting in a loss of secondary confinement

Additionally, the main lateral force resisting members of the Support Building and Building 412 are DBT designed to protect the WHB from their structural failure.

Section 5.2.4.1 discusses in greater detail: (1) the evaluation of safety SSCs, and (2) the applicability of functional and performance requirements (system evaluation) and controls (TSRs). Due to the importance of DBT qualification, and programs relating to configuration and document control, quality assurance, preventative maintenance and inspection, the WIPP RH WAC, and the WIPP Emergency Management Program, in the WIPP defense-in-depth strategy for this accident, TSR ACs are derived in Chapter 6 and required in the WIPP TSR Document.

5.2.3.9 RH8 Aircraft

Scenario Description - The possibility of an aircraft crash into the WHB has been identified as part of the HAZOP performed for the CH TRU waste handling system. This scenario represents an external accident which may involve the potential breach of waste containers. It is postulated that a military or civilian aircraft crashes into the WHB. DOE-STD-3014-96, Accident Analysis for Aircraft Crash into Hazardous Facilities,[53] provides criteria for the development of frequencies of aircraft accidents used in analyses for nuclear power plants and for crash frequency contributions associated with airport operations (takeoffs and landings), and federal airway activity (overflights).

As described in Chapter 2, two federal ten-mile wide airways (one jet route and one low-altitude route) pass within five miles of the WIPP. Traffic data show that the combined traffic is about 28 instrument flight rule flights per day.

There are no airports or approaches within a five-mile radius of the WIPP. The nearest airstrip, twelve miles north of the site, and privately owned by Transwestern (TW) Pipeline Co. is no longer in use and TW filed for abandonment in 1990 with the Federal Aviation Administration. The nearest commercial airport is in Carlsbad (28 miles to the west).

There are no military facilities within a five mile radius of the WIPP, however, some military installations in New Mexico and Texas have operations that might affect the WIPP (the closest is Holloman Air Force Base, 138 miles NW of the site).

Using DOE-STD-3014-96[53], the total aircraft hazard probability (combined airway and airport) at the WIPP site is 3.6E-07/yr.

Preventive and Mitigative Features - Air space above facility not part of normal flight patterns and WIPP is in a remote location.

Estimated Frequency - The HAZOP Team qualitatively estimated the frequency of occurrence of an aircraft crash to be beyond extremely unlikely ($10^{-6} \geq$ frequency). This estimated frequency of occurrence has also been documented in ITSC-WIPP-2000-01, Estimate of Aircraft Impact Frequency and Consequences at the WIPP,[54] considering the total aircraft hazard probability (combined airway, airport, and military designated airspace operations probability of an aircraft crash).

Source term Development - The frequency of the accident scenario is beyond extremely unlikely therefore, source term development is unnecessary.

Estimated Consequences and Comparison to Risk Evaluation Guidelines - The frequency of the accident scenario is beyond extremely unlikely therefore, consequence analysis is unnecessary.

Assessment of Immediate Worker Consequences- As discussed in Section 5.2.1.2, this scenario is not evaluated for immediate worker consequences.

Safety Structures, Systems, and Components - This scenario is considered beyond extremely unlikely and no hazardous material is postulated to be released during this scenario, therefore, no Safety Class or Safety Significant SSCs are required.

There are no defense-in depth SSCs applicable to this scenario, per the criteria provided in Chapter 3, Section 3.1.3.

5.2.3.10 NC1 Fire in the Hot Cell

Scenario Description - The 10-160B HAZOP[56] postulated a waste drum breach from a fire in the Hot Cell. The HAZOP[56] postulated two hazardous events (9-1 and 11D-1) that could result in a fire in the Hot Cell which could cause a significant release of radioactivity.

Hazardous event 9-1 postulates a fire in the Hot Cell that causes a fire in a drum(s). The fire is postulated to occur at the point in the processing of the waste from a 10-160B cask when the waste drums have been removed from the cask and are placed in the Hot Cell for processing and storage until they are placed in a facility canister for final disposal. The possible cause of the fire is an electrical short. This event would be a fire external to the waste drums. The external fire would have to be of sufficient severity to cause a fire in a drum or multiple drums, resulting in the release of the material contained in the drums.

Hazardous event 11D-1 postulates a fire in the Hot Cell that causes the release of radioactive materials. The fire is postulated to occur during the transfer of the waste drums to the facility canister. Part of the process is welding the lid to a facility canister. The possible cause of the fire is ignition of combustibles inside a facility canister due to heat generated by welding. This event is different from Event 9-1 in that the fire is internal to the waste drum. The potential release is limited to the waste drums in a facility canister being prepared for disposal. At the time the 10-160B HAZOP was performed, the design of the facility canister required the lid to be welded to the canister body. The facility canister design was changed so that the lid mechanically locks to the canister body and welding is no longer performed. Since welding is no longer performed, further analysis will not be performed on event 11D-1.

Preventive and Mitigative Features - General preventive and mitigative measures identified in the HAZOP for this specific scenario are listed in Table 5.1-10.

Estimated Frequency - The HAZOP Team qualitatively estimated the frequency of occurrence of a fire in the Hot Cell to be in the anticipated range (10^{-1}/yr $\geq$ frequency $>10^{-2}$/yr) for hazardous event 9-1. However, based on a quantitative evaluation using conservative assumptions documented in Appendix A and below, the overall frequency of the fire in the Hot Cell while containing stored waste (event 9-1) is extremely unlikely (10^{-4} $\geq$ frequency $>10^{-6}$/yr). The following assumptions are used in this analysis:

- Drums meet WIPP WAC for flammable gases
- Combustible materials program will limit the combustible materials in the Hot Cell
- The Hot Cell walls constitute an effective fire barrier to keep a fire originating outside the Hot Cell from propagating to the Hot Cell
- No more than 2080 waste drums from 10-160B casks are processed through the Hot Cell in one year

This accident is initiated by hazardous event 9-1. The frequency or estimated annual likelihood of occurrence of Event 9-1is determined by the following factors:

- The likelihood that an electrical short occurs in the Hot Cell that initiates a fire.
- The likelihood that there is sufficient combustible material in the Hot Cell to generate sufficient heat to ignite the contents of a waste drum.
- The likelihood that there is sufficient oxidant in the drum to support a sustained fire.

The frequency of a fire occurring in the Hot Cell can be estimated as:

Frequency of Fire (per year) = Probability of electrical short igniting fire x Probability of sufficient combustible material in Hot Cell to ignite drum contents x Probability of sufficient oxidant x Number of drums handled per year

In order for an electrical short to ignite a fire, an electrical fault must occur and the protective device on the circuit (circuit breaker or fuse) must fail to operate to clear the fault. Per WSRC-TR-93-262,[21] electrical faults (including short circuits) have frequencies on the order of 1E-06 to 1E-07 per hour or 9E-03 to 9E-04 per year per termination or cable. If it is conservatively assumed that an electrical short in the equipment in the Hot Cell occurs with waste stored in the Hot Cell, then the probability of a fire initiated by an electrical short can be approximated as the demand failure of the circuit breaker or fuse. From WSRC-TR-93-262,[21] the failure of a circuit breaker or fuse is 5.0E-04/demand. Therefore, the probability of an electrical short igniting a fire in the Hot Cell in one year can be estimated as 5.0E-04. Note that probabilities are dimensionless.

The probability that there is sufficient combustible material in the Hot Cell that a large enough fire to result in igniting the material in a waste drum is based on a violation of the procedural requirements of the combustible control program for WIPP. Therefore, the probability of having sufficient combustible material in the Hot Cell to generate a large enough fire to ignite the waste material in a drum can be equated to a human error in failing to properly follow procedures. Table D-1 of the WIPP CH SAR[6], provides estimated human error probabilities. For this case, it is assumed that the failure to properly meet the combustible control program requirements would involve an error to accomplish a clear, unambiguous task and the failure of a checker (not independent in time) to detect the error. From Table D-1 of the WIPP CH SAR[6], the human error probability to accomplish a clear unambiguous task is 1.0E-03/demand and the failure of a checker to identify the error is 1.0E-01/demand. If it is conservatively assumed that the handling of each drum in the Hot Cell represents the opportunity to violate the combustible loading control program, then the probability of having sufficient combustibles to generate a large enough fire to ignite the waste material in a drum is:

Probability of sufficient combustible material in Hot Cell to ignite drum contents = 1.0E-03 x 1.0E-01 = 1.0E-04

The probability that there is sufficient oxidant in a waste drum to support a sustained fire is provided in Table D-1 of the WIPP CH SAR[6]. It provides a probability of 4.2E-03.

The total number of 10-160B casks that will be handled in the RH facility during one year is estimated to be 208 in Table D-1 of the WIPP CH SAR[6]. There are up to 10 waste drums in each 10-160B cask. Therefore, the total number of waste drums handled in one year is 2,080. (Note that using the total number of waste drums that are handled in the Hot Cell during one year is a conservative, bounding assumption. At most, only 10 waste drums not in facility canisters can be stored in the Hot Cell at any one time and each waste drum is handled only once. A more accurate estimate of the number of drums at risk is 10.)

Using the above values, the frequency of Event 9-1 occurring can be estimated as: Frequency of Fire (per year) = 2080 drums/year x 5.0E-04 x 1.0E-04 x 4.2E-03 = 4.0E-07/year. This frequency places the event Fire in Hot Cell While Containing Stored Waste (9-1) in the "extremely unlikely" frequency bin (10^{-4}/yr $\geq$ frequency $>10^{-6}$/yr).

Source Term Development - Since event 11-D1 can not occur, the source term is developed specifically for event 9-1.

Material at Risk - Both the radiological and non-radiological hazardous material are at risk of being released as the result of a fire in the Hot Cell that results in breach of a waste drum. A conservative approach in determining the accident consequences is taken. As discussed in Section 5.2.1.1, ten waste drums from a 10-160B cask can be stored in the Hot Cell after they are unloaded from the cask with the entire 20 PE-Ci inventory located in a single waste drum (CI = 20 PE-Ci). The storage of up to six fully loaded facility canisters in the Hot Cell is allowed for 90 days. The maximum number of drums stored in the Hot Cell at any one time is 28. Because the cask holds 10 drums, at times one of the canisters may contain one or two waste drums from another cask shipment and be unsealed in the inspection station. However, the combustible loading of the Hot Cell is very low. All of the remote handling equipment in the Hot Cell is electrically operated, there are no hydraulics and therefore no hydraulic oil. The only significant combustible material in the Hot Cell is the electrical cable insulation. Since the release of material in this scenario requires the fire outside of the drums to heat the drum contents to the point where the combustible materials in a drum ignites, the limited combustible loading in the Hot Cell will limit the number of drums that can be heated to a high enough temperature to ignite. Additionally, the drums stored in the facility canisters are provided a second confinement barrier by the canister. These drums are effectively shielded from the direct effects of a fire. Therefore, only the ten drums stored in the Hot Cell awaiting placement in a facility canister are at risk from a fire. There is insufficient combustible loading and direct access to the drums by the fire (some of the drums will be shielded from the fire by other drums) to reasonably expect that multiple drums would be heated to ignition temperature. Therefore, it will be assumed that only one waste drum is heated to a high enough temperature for the contents to ignite, resulting in a release of the radiological material (CD = 1). The radiological MAR for this event is 20 PE-Ci (CD x CI).

As discussed in Section 5.2.1.1, the non-radiological MAR of one waste drum is 243 pounds. The total hazardous chemical compound inventories for the waste drums are shown in Table 5.1-3.

Damage Ratio - As discussed in Section 5.2.1.1, the analysis performed for the CH TRU Central Characterization facility showed that only 16.3 percent of the combustible material in the waste drums is actually burned (DR = 0.163).

Airborne Release Fraction - The ARF for combustible materials in a drum is 5.0E-04 and the ARF for noncombustible materials in a drum is 6.0E-03. These values represent bounding ARFs for the burning of contaminated packaged mixed waste and the heating of noncombustible contaminated surfaces (DOE-HDBK-3010-94, subsection 5.2.1.1 and 5.3.1).[4]

Respirable Fraction - The respirable fractions for the combustible solids (CRF) and noncombustible solids (NCRF) are taken directly from DOE-HDBK-3010-94[4]. The CRF is 1.0 and the NCRF is 0.01.

Leak Path Factor - The scenario of a fire in the Hot Cell would result in the release of the material from the waste drums stored in the Hot Cell to the Hot Cell atmosphere. The Hot Cell atmosphere is exhausted through a HEPA filter bank in the Hot Cell filter gallery and then to the WHB exhaust header. As discussed in Section 5.2.1, the LPF for this scenario is 1.0E-06 with mitigation and 1.0 for no-mitigation.

The LPF due to the HEPA filters is only applicable to the material released as particulates. The liquid hazardous material is vaporized due to the thermal stress of the fire. The HEPA filters are not effective in removing vapor. However, credit is taken for plateout of mercury by assuming 50 percent of the mercury is removed due to plateout (LPF = 0.5). The LPF for all other liquid hazardous materials is 1.0.

Estimated Noninvolved Worker and MEI Consequences and Comparison to Risk Evaluation Guidelines - Based on the values for the source term variables as presented above, the worst-case, no-mitigation MEI and noninvolved worker consequences (Appendix E Tables E-18 and E-19) of event 9-1 are well within the radiological and non-radiological risk evaluation guidelines for the extremely unlikely range. The non-radiological results meet the guidelines (i.e., the sum of ratios < 1) when all the chemicals are added (Tables E-20 and E-21).

Assessment of Immediate Worker Consequences - No immediate worker consequences are calculated for NC1 because no workers are in the Hot Cell, the operation is done remotely.

Safety Structures, Systems, and Components - Based on the consequence analysis results for this accident, Safety Class or Safety Significant SSCs are not required. The following input data and assumptions are used in the frequency and source term analyses:

- Maximum PE-Ci content of 10-160B cask is 20 PE-Ci.
- A combustible materials control program is established for the Hot Cell that ensures insufficient fuel and location of fuel so that a fire in the Hot Cell would not be of sufficient magnitude to damage multiple waste drums.
- The Hot Cell walls constitute an effective fire barrier to keep a fire originating outside the Hot Cell from propagating into the Hot Cell and to keep a fire that originates inside the Hot Cell from propagating to outside areas.
- The maximum hazardous material weight contained in a waste drum is 243 pounds.
- No more than six fully loaded and one partially loaded facility canisters are stored in the Hot Cell at any one time. Also, only ten waste drums removed from a 10-160B cask and not in facility canisters can be in the Hot Cell.
- The hazardous chemical inventory in the RH waste is the same as for the CH waste.
- A 10-160B cask can contain no more than 10 waste drums.
- Total number of waste drums handled in one year in the Hot Cell is 2080.

The defense-in-depth SSCs which are applicable to this scenario, per the criteria in Chapter 3, Section 3.1.3 are assigned as follows:

- Vented DOT Type A waste drum - primary confinement
- WHB Ventilation System - secondary confinement
- Design of Hot Cell - designed to minimize fires

5.2.3.11 NC2 Fire in the Underground

According to Section 5.2.3.1 (RH1), the fire in the underground that causes a release of hazardous materials (radioactive and chemicals) from the facility cask or from a 72B waste canister is not possible. Therefore, a fire during processing the facility cask containing a facility canister of 10-160B waste in the underground would not cause a release of the hazardous materials. The design features and controls credited in the Section 5.2.3.1 will be applicable during the processing of 10-160B waste.

5.2.3.12 NC3 Loss of Confinement in the WHB

Scenario Description - The 10-160B HAZOP [56] postulated a LOC of the waste material in the WHB (CUR, Hot Cell, Transfer Cell, or RH Bay). Twenty hazardous events (1B-6, 4D-1, 4F-1, 4G-1, 4H-1, 5BD-1, 5CE-1, 5CE-2, 9-5, 9AC-1, 10A-1, 10B-1, 10BF-1, 11D-3, 11F-1, 12E-1, 12E-2, 12E-3, 12E-4, and 14B-1) were postulated that could result in a LOC of the waste material in the WHB. The LOC event could cause a significant release of radioactivity.

The events are grouped so that similar events are treated together. Each group will have similar consequences and the consequences for the group as a whole are determined by the most severe of the hazardous events within each group. Note that although the hazardous events in each group may have similar consequences, the frequency of the events in the group may vary. Where the events in a group have different frequencies, the consequences for the group (determined by the most severe event) are compared to the appropriate guidelines for each frequency range contained within the group. This will ensure that the most severe consequences are evaluated against the most limiting evaluation criteria. To simplify the discussion, the groups within the NC3 category are numbered NC3-A, NC3-B, etc.

The general assumptions related to the training, operations and maintenance practices at WIPP that apply to all of the individual LOC event frequency analyses. The following assumptions are used in this analysis:

- WIPP equipment operators are highly skilled and extensively trained in their duties. The operators are highly competent and reliable in the performance of waste handling operations.
- WIPP maintenance programs, especially related to cranes, hoists, and forklifts, is extensive and intended to provide better than average reliability.
- WIPP procedures require pre-operational checks of all waste handling equipment to verify correct performance at the beginning of each shift.
- The 140/25-ton crane and the Hot Cell crane are similar in design, operation and maintenance to the TRUDOCK crane and, therefore, have a similar reliability.
- If a waste drum is placed in a facility canister and the canister is not sealed and left in the Hot Cell awaiting the next 10-160B cask processing, there is no activity that would place the waste drum at risk of being impacted or punctured.
- No more than 208 10-160B casks are processed through the RH Bay in one year
- No more than 693 facility canisters containing waste drums from 10-160B casks are processed through the Hot Cell in one year
- No more than 2080 waste drums from 10-160B casks are processed through the Hot Cell in one year
- Procedures are in place to limit the movement of compressed gas cylinders while 10-160B casks are present in the RH Bay
- Procedures are in place to limit vehicle movement while 10-160B casks are present in the RH Bay

NC3 - Airborne Release Fraction

The two types of accident stresses in the LOC in the Hot Cell and RH Bay accident scenarios are; impact stresses due to dropping and impact stresses due to puncture. Both types of stresses have the same potential for generating airborne releases.

There are two applicable ARFs for materials exposed to impact stresses generated by dropping an object on the waste drums or puncturing the waste drums given in DOE-HDBK-3010-94.[4] One ARF is for combustible solid packaged waste (CARF) and one is for non-combustible solid packaged waste (NCARF). In this analysis, the waste in the drums processed through the Hot Cell and RH Bay is assumed to contain both combustible and non-combustible solid waste. As a conservative, bounding assumption, it is assumed that the solid waste in the drums consists of 5 percent combustible waste (CF = 0.05) and 95 percent non-combustible waste (NCF = 0.95) for the LOC events. The combination of ARF and RF for non-combustibles exposed to impact stresses is higher than for combustibles. This is consistent with the assumptions used in the accident analysis for the CH waste reported in the WIPP CH SAR[6] and with the assumptions used in the accident analysis for the 72B cask.

In addition to being either combustible or non-combustible, the hazardous materials in the waste drums may be either in a gaseous, liquid or solid form. All of the radiological material in the waste is assumed to be in a solid form. The non-radiological hazardous materials may be either in a gaseous, liquid or solid form. The hazardous materials that are in gaseous form are the VOCs shown in Table 5.1-2. It is assumed that the VOCs are instantaneously released from a breached waste drum. The VOCs have an ARF of 1.0 regardless of whether they are combustible or non-combustible.

For the liquid hazardous materials, the ARF is developed based on the assumption that the material is not in a free-standing form. In other words, the liquid is assumed to be absorbed into solid waste material such as rags, kim wipes or other material. The liquid hazardous material is assumed to respond to the accident stresses in the same manner as the solid material in which it is absorbed.

For the non-gaseous radiological and hazardous materials, the ARF depends on whether or not the material is combustible. The bounding value of CARF from DOE-HDBK-3010-94[4], Section 5.2.3.2 for contaminated combustible material which is subjected to impact and breach of the waste drum is 1.00E-03 (CARF = 1.00E-03).

For the non-combustible non-gaseous waste material, the bounding value for NCARF is taken directly from DOE-HDBK-3010-94[4], Section 5.3.3.2.2, which gives a bounding value of 1.0E-03 for materials that do not undergo brittle fracture (NCARF = 1.0E-03).

<u>NC3 - Respirable Fraction</u>

The respirable fractions for the combustible non-gaseous material (CRF) and non-combustible non-gaseous material (NCRF) are taken directly from DOE-HDBK-3010-94[4]. The bounding CRF is 0.1 (page 5-4[4]) and the bounding NCRF is 1.0 (page 5-7[4]). For the VOCs, the CRF and NCRF are both set equal to 1.0. Since the VOCs are assumed to be in gaseous form, all of the VOCs will be respirable.

<u>NC3 - Leak Path Factor</u>

For the LOC accident scenarios that occur in the Hot Cell (NC3-A, NC3-C, and NC3-E) the hazardous material is released to the Hot Cell atmosphere which is exhausted through a HEPA filter bank in the filter gallery and then to the exhaust header. As discussed in Section 5.2.1, the LPF is 1.0E-06 for the mitigated case and 1.0 for the no-mitigation case.

For the LOC accident scenarios that occur outside the Hot Cell (NC3-B, NC3-D, NC3-F, NC3-G, and NC3-H) the release of the hazardous material is to the WHB atmosphere. The WHB atmosphere is exhausted through a HEPA filter bank in the exhaust fan mechanical room and then to the exhaust header. The LPF is 1.0E-06 for the mitigated case and 1.0 for the no-mitigation case. The LPF for the VOCs is 1.0 even for the mitigated case.

NC3-A Dropped Object on Waste Material in Hot Cell Accident Scenario:

NC3-A is composed of events 4F-1, 4H-1, 5CE-2, 9-5, and 9AC-1, all of which involve the dropping of an object during waste handling operations in the Hot Cell.

Events 4F-1 and 4H-1 involve drops occurring while removing the 10-160B cask lid. Hazardous event 4F-1 postulates dropping the shield plug onto a facility canister stored in the Hot Cell, while hazardous event 4H-1 postulates dropping a 10-160B cask lid onto the waste in the Hot Cell. The causes of both events are: human error and/or equipment malfunction. The potential consequences of both events are: breach of facility canisters and/or drums, spread of contamination, offsite and onsite consequences, release of hazardous waste and shut down operations. Breach of a waste canister or drum could cause a significant release of radioactivity to the environment.

The frequency of event 4F-1 is a function of the number of 10-160B casks that are processed each year and the probability of dropping the shield plug while it is being removed. The maximum number of 10-160B casks that will be processed in one year is 208. Therefore, the shield plug will be removed by using the Hot Cell crane 208 times a year. From Table D-9 of the WIPP CH SAR[6] the probability of a crane drop per lift due to all mechanisms is 3.4E-06. Therefore, the frequency of event 4F-1 is:
208 lifts/yr * 3.4E-06 = 7.1E-04/yr or "unlikely" (10^{-2}/yr $\geq$ frequency >10^{-4}/yr).

The frequency of event 4H-1 is a function of the number of 10-160B casks processed each year and the probability of a crane drop. Therefore, the frequency of event 4H-1 is the same as the frequency of event 4F-1 (7.1E-04/yr) or "unlikely" (10^{-2}/yr $\geq$ frequency >10^{-4}/yr).

Hazardous event 5CE-2 postulates dropping a loaded drum carriage inside the Hot Cell onto waste drums or a facility canister. The causes of this event are human error and equipment failure. The frequency of event 5CE-2 is a function of the number of waste drum carriages handled per year and the probability of dropping the carriage while it is being lifted. Since there are two drum carriages in each 10-160B cask, if 208 10-160B casks are processed each year, 416 drum carriages will be lifted. The frequency of event 5CE-2 is: 416 lifts/yr * 3.4E-06 = 1.4E-02yr or "unlikely" (10^{-2}/yr $\geq$ frequency >10^{-4}/yr).

Hazardous event 9-5 postulates the shield plug lift fixture falls (knocked) over. The causes of this event are the fixture is hit by a crane, a load on a crane, or equipment. The potential consequences of this event are: broken shield window (loss of shielding), onsite/offsite consequences, facility worker exposure and personnel injury.

The frequency of event 9-5 is a function of the number of crane operations that are close to the shield plug lifting fixture stand and the probability of a human error that results in striking the shield plug lifting fixture with the crane or its load such that it falls over and strikes waste stored in the Hot Cell. This event occurs during preparation of a facility canister for loading with waste drums. There are 208 10-160B casks processed per year. Each 10-160B cask could contain up to ten waste drums so that up to 2080 waste drums a year could be processed through the Hot Cell. Each facility canister can hold three waste drums. Therefore, a total of (2080/3 =) 693 facility canisters per year can be processed in the Hot Cell and 693 crane movements of the facility canisters will occur in a year. From WSCR-TR-93-581[31], the conservative high probability of a remotely operated crane striking a stationary object is 3E-03 per crane operation. This probability is assumed to apply in this case by assuming that the human error failure rate dominates the equipment (hardware) failure rate that could result in the crane striking the lifting fixture. The probability that a waste drum is mis-positioned and left in a location where it can be struck by the falling shield plug lift fixture is modeled as a human error for failure to properly follow procedures. Table D-1 of the WIPP CH SAR[6], provides estimated human error probabilities. For this case, it is assumed that the failure to properly follow procedures in the placement of waste drums stored in the Hot Cell would involve an error to accomplish a clear, unambiguous task and the failure of a checker (not independent in time) to detect the error. From Table D-1 of the WIPP CH SAR[6], the human error probability to accomplish a clear unambiguous task is 1.0E-03/demand and the failure of a checker to identify the error is 1.0E-01 per demand. It is also conservatively assumed when the shield plug lifting fixture impacts a waste drum, the waste drum fails. The frequency of event 9-5 is: 693 lifts/yr * 3.00E-03 * 1.00E-03 * 0.1 = 2.0E-04/yr or "extremely unlikely" (10^{-4}/yr $\geq$ frequency > 10^{-6}/yr).

Hazardous event 9AC-1 postulates dropping an empty facility canister on stored waste drums in the Hot Cell. The causes of this event are human error, equipment failure, and grapple failure. The frequency of event 9AC-1 is a function of the number facility canisters handled per year and the probability of dropping a facility canister while it is being lifted. There are 208 10-160B casks processed per year. Each 10-160B cask could contain up to 10 waste drums so that up to 2080 waste drums a year could be processed through the Hot Cell. Each facility canister can hold three waste drums. Therefore, a total of (2080/3 =) 693 facility canisters per year can be processed in the Hot Cell. From Table D-9 of the WIPP CH SAR[6], the probability of a crane drop per lift due to all mechanisms (equipment failure and human error) is 3.4E-06. The frequency of event 9AC-1 is: 693 lifts/yr * 3.4E-06 = 2.35E-03/yr or "unlikely" (10^{-2}/yr $\geq$ frequency >10^{-4}/yr). The consequences of the NC3-A will be compared against the Evaluation Guidelines for the "unlikely" frequency range.

As discussed in Section 5.2.1.1, ten waste drums from a 10-160B cask can be stored in the Hot Cell after they are unloaded from the cask with the entire 20 PE-Ci inventory in a single waste drum (CI = 20 PE-Ci). Additionally, the storage of up to six fully loaded facility canisters in the Hot Cell is allowed for 90 days. The maximum number of drums stored in the Hot Cell at any one time is 28. Because the cask holds ten drums, at times one of the canisters may contain one or two waste drums from another cask shipment and be unsealed in the inspection station. However, the waste drums that are located in the facility canisters are protected from the direct effects of a dropped object (double confinement). Therefore, only the ten waste drums stored in the Hot Cell outside of a facility canister and awaiting placement in a facility canister are subject to the direct effects of a dropped object. Since it is assumed that all of the radiological material from an entire 10-160B cask is located in a single waste drum, assuming that all 10 drums are impacted is equivalent to assuming that the one drum containing all of the radiological material is damaged. Therefore, for the radiological source term analysis, it will be assumed that only one waste drum is breached by a dropped object in the Hot Cell, resulting in a release of the radiological material (CD = 1). The MAR for this event is 20 PE-Ci (CD x CI).

As discussed in Section 5.2.1.1, the average weight fractions are used with the total weight of waste in ten drums to determine the total non-radiological MAR. Each waste drum can contain 243 pounds of hazardous material for a total weight of 2430 pounds of hazardous material per 10-160B cask. The results are shown in Table 5.1-3. The gas space volume in the waste drums is assumed to be the same as that in the CH waste (70 percent void space) and a total volume of 55 gallons for each waste drum. The VOC mass in the waste drum head space is shown in Table 5.2-1.

It is assumed that only the ten waste drums stored in the Hot Cell, not in facility canisters, are subject to the effects of a dropped object. Since all ten of the drums could be impacted by the dropped object, it is assumed that the non-radiological MAR is the content of ten waste drums (CD = 10). The non-radiological MAR = 2430 pounds.

The DR in this case is determined based on the amount of damage the waste drum receives as a result of the impact and how much of the contents are exposed. As discussed in Section 5.2.1.1, the shield plug is approximately four times the 1000 pound weight of a waste drum, it is assumed that the impact of the shield plug on a waste drum would result in a DR four times the DR for dropping a 1000 pound waste drum from the same height. For this event it is conservatively assumed that the DR = 0.1 (4 x 0.025).

Estimated Noninvolved Worker and MEI Consequences and Comparison to Risk Evaluation Guidelines - Based on the values for the source term variables as presented above, the worst-case, no-mitigation MEI and noninvolved worker consequences (Appendix E Tables E-22 and E-23) of NC3-A are well within the radiological and non-radiological risk evaluation guidelines for the unlikely range. The non-radiological results meet the guidelines (i.e., the sum of ratios < 1) when all the chemicals are added (Tables E-24 and E-25).

Assessment of Immediate Worker Consequences - No immediate worker consequences are calculated for NC3-A because no workers are in the Hot Cell where the event occurs.

<u>NC3-B Dropped Object on Waste Material Outside Hot Cell Accident Scenario:</u>

NC3-B is composed of events 4G-1 and 5BD-1, which involve the dropping of an object during waste handling operations outside the Hot Cell.

Hazardous event 4G-1 postulates dropping a 10-160B cask lid onto the cask and its drums. The causes of this event are human error and equipment failure. The frequency of event 4G-1 is a function of the number of 10-160B casks that are processed each year and the probability of a cask lid being dropped while it is being removed. The maximum number of 10-160B casks that will be processed in one year is 208. Therefore, a 10-160B cask lid will be removed by using the crane in the Hot Cell 208 times a year. From Table D-9 of the WIPP CH SAR[6], the probability of a crane drop per lift due to all mechanisms is 3.4E-06. The frequency of event 4G-1 is: 208 lifts/year * 3.4E-06 = 7.1E-04/year or "unlikely" (10^{-2}/yr $\geq$ frequency >10^{-4}/yr).

Hazardous event 5BD-1 postulates dropping the drum carriage lifting fixture onto the drums. The causes of this event are human error and equipment failure. The frequency of event 5BD-1 is a function of the number of 10-160B casks processed each year and the probability of dropping the drum carriage lifting fixture while preparing to remove the waste drum carriages from the cask. 208 10-160B casks will be processed in one year is 208. Since there are two drum carriages in each 10-160B cask, the total number of times the drum carriage lifting fixture will be used is 416 per year. From Table D-9 of the WIPP CH SAR[6], the probability of a crane drop per lift due to all mechanisms is 3.4E-06. The frequency of event 5BD-1 is: 416 lifts/year * 3.4E-06 = 1.4E-03/year or "unlikely" (10^{-2}/yr $\geq$ frequency >10^{-4}/yr).

It is assumed that each of these individual events is independent, then the frequency of the Dropped Object on Waste Material Outside Hot Cell event can be assumed to be equivalent to the highest frequency of the individual events for the purposes of determining which Evaluation Guidelines apply.

Each of the events of NC3-B has a frequency in the "unlikely" range (10^{-2}/yr $\geq$ frequency >10^{-4}/yr). The consequences of NC3-B are compared against the Evaluation Guidelines for the "unlikely" frequency range.

For this accident scenario it is assumed that the entire 20 PE-Ci inventory is located in a single waste drum (CI = 20 PE-Ci). This event involves dropping an object on the waste drums in the 10-160B cask while it is in the CUR. Only one 10-160B cask can be processed through the CUR at one time, therefore only the ten waste drums contained in the 10-160B cask being processed are subject to the direct effects of a dropped object. Since it is assumed that all of the radiological material from an entire 10-160B cask is located in a single waste drum, assuming that all ten drums are impacted is equivalent to one drum containing all of the radiological material is damaged. For the radiological source term analysis, it is assumed that only one waste drum is breached by a dropped object, resulting in a release of the radiological material (CD = 1). The MAR for this event is 20 PE-Ci (CD x CI).

For the non-radiological MAR it is assumed that only the ten waste drums contained in the 10-160B cask being processed in the CUR are subject to the effects of a dropped object. However, the waste drums in the 10-160B cask are in two drum carriages, each containing 5 waste drums. Only the waste drum carriage on the top would be directly impacted by the dropped object. Therefore, it is assumed that the non-radiological MAR is the content of 5 waste drums (CD = 5). The non-radiological MAR is limited to the hazardous material content of 5 waste drums or 1215 pounds.

The DR in this case is determined based on the amount of damage the waste drum receives as a result of the impact and how much of the contents are exposed as a result. As discussed above it is conservatively assumed that the DR is (4 x 0.025 =) 0.1 for this event.

Estimated Noninvolved Worker and MEI Consequences and Comparison to Risk Evaluation Guidelines - Based on the values for the source term variables as presented above, the worst-case, no-mitigation MEI and noninvolved worker consequences (Appendix E Tables E-26 and E-27) of NC3-B are well within the radiological and non-radiological risk evaluation guidelines for the unlikely range. The non-radiological results meet the guidelines (i.e., the sum of ratios < 1) when all the chemicals are added (Tables E-28 and E-29).

Assessment of Immediate Worker Consequences - No immediate worker consequences are calculated for NC3-B because no workers are in the CUR where the event occurs.

NC3-C Dropped Drum or Canister in Hot Cell Accident Scenario:

NC3-C is composed of hazardous events 10B-1, 10BF-1, and 11F-1. All of which involve dropping a waste drum or loaded facility canister inside the Hot Cell.

Hazardous event 10B-1 postulates that while lifting a drum, the drum lid comes off. The causes of this event are human error, equipment failure and drum lid failure. The frequency of event 10B-1 is a function of the number of drums lifted for placement in a facility canister each year and the probability of the drum lid failing during the lift. From examination of the drum and lifting process, it is concluded that the lid falling off during a lift is not a credible event. The ICC-17C 55 gallon drum has a cable lift fixture attached below the first rolling hoop prior to initial drum loading as shown in Figure 4.2-11. The loaded drums were placed in the drum carriage for shipment using the cable lift fixture at the shipping site. The lift cables are placed over the crane hook and the lift executed. This exerts a force on the drum lid ring tending to hold the lid in place. The lift cables are symmetric around the drum to ensure there is no load shift. During the lift, the lift cable forces hold the lid in place.

Hazardous event 10BF-1 postulates while lifting a drum, the drum is dropped. The causes of this event are human error and equipment failure. The frequency of event 10BF-1 is a function of the number of waste drums that are processed through the Hot Cell each year and the probability of dropping a drum while lifting it to be placed into a facility canister. The maximum number of 10-160B casks that will be processed in one year is 208. Since there are ten drums in each 10-160B cask, the total number of times a drum will be lifted to place it in a facility canister is 2080 per year. From Table D-9 of the WIPP CH SAR[6], the probability of a crane drop per lift due to all mechanisms is 3.4E-06 per demand. Additionally, since the drum must be damaged to provide the potential for the release of hazardous material, the probability of damaging a drum due to the impact must be included. From Table D-1of the WIPP CH SAR[6], the probability that one drum in a seven pack that is dropped ten feet fails is given as 0.62. However, this probability includes the crushing effect of the other drums in the package. Since in this case a single drum is dropped, the probability of failure would be lower. Therefore, the probability that a drum is failed by a drop in the Hot Cell is assumed to be 0.3, half the probability from CH SAR [6]. The frequency of event 10BF-1 is: 2080 lifts/year * 3.4E-06 * 0.3 = 7.1E-03/year or "unlikely" (10^{-2}/yr $\geq$ frequency >10^{-4}/yr).

Hazardous event 11F-1 postulated dropping a loaded facility canister in the Hot Cell. The causes of this event are canister lid failure, grapple failure, human error and sheared crane cables. The frequency of event 11F-1 is a function of the number of facility canisters that are processed through the Hot Cell each year and the probability of dropping a canister while lifting. The maximum number of 10-160B casks that will be processed in one year is 208. Since there are ten drums in each 10-160B cask, the total number drums will be processed is 2080 per year. Since a facility canister can hold 3 drums, a total of (2080/3) or 693 facility canisters will be processed per year. From Table D-9 of the WIPP CH SAR[6], the probability of a crane drop per lift due to all mechanisms is 3.4E-06. The frequency of 11F-1 is: 693 lifts/year * 3.4E-06 =2.4E-03/year or "unlikely" (10^{-2}/yr $\geq$ frequency >10^{-4}/yr).

Each of the events of NC3-C has a frequency in "unlikely" range (10^{-2}/yr $\geq$ frequency >10^{-4}/yr). Therefore, the consequences of NC3-C are compared against the Evaluation Guidelines for the "unlikely" frequency range.

The radiological MAR for this accident scenario assumes that the entire 20 PE-Ci inventory is located in a single waste drum (CI = 20 PE-Ci). This event involves dropping a waste drum while loading it into a facility canister or dropping a loaded facility canister in the Hot Cell while preparing it for disposal. Since a loaded facility canister contains three waste drums, failing the three waste drums in the canister due to dropping the canister would require failure of not only the drums but also of the canister (double confinement). The DR for double confined waste releases is much less than for single confined waste (a factor of ten). Therefore, the release from the waste drums in the loaded facility canister is bounded by the release from a dropped waste drum. The other two hazardous events in this accident involve failure of the lid of a waste drum during lifting (a single drum damaged) and dropping a waste drum on top of another during lifting (two waste drums damaged). Since it is assumed that all of the radiological material from an entire 10-160B cask is located in a single waste drum, it is possible that the drum dropped and the drum on which it is dropped could both be the hot loaded drum from separate 10-160B casks. This could occur if the drum left in a partially loaded facility canister is the one containing all of the radiological inventory and the drum dropped on top of it is the drum containing all of the radiological inventory from another 10-160B cask. For the radiological source term analysis, it will be assumed that two waste drums are breached by dropping a waste drum during lifting in the Hot Cell, resulting in a release of the radiological material (CD = 2). The MAR for this event is 40 PE-Ci (CD x CI).

As with the radiological MAR, in determining the non-radiological MAR it is assumed that at most two waste drums in the Hot Cell are subject to the effects of dropping a drum during lifting. It is assumed that the non-radiological MAR is the content of two waste drums (CD = 2). Therefore, the non-radiological MAR is limited to the hazardous material content of two waste drums or 486 pounds.

The DR in this scenario is determined based on the amount of damage the two waste drums receive as a result of the impact and how much of the contents are exposed as a result. The waste drums are DOT Type A containers. The drop in this event is during lifting operations and is assumed to be greater than four feet. From section 5.2.1.1, the DR for drops of waste containers from heights greater than five feet but less than or equal to ten feet is 0.025. The DR is 0.025 for this event.

Estimated Noninvolved Worker and MEI Consequences and Comparison to Risk Evaluation Guidelines - Based on the values for the source term variables as presented above, the worst-case, no-mitigation MEI and noninvolved worker consequences (Appendix E Tables E-30 and E-31) of NC3-C are well within the radiological and non-radiological risk evaluation guidelines for the unlikely range. The non-radiological results meet the guidelines (i.e., the sum of ratios < 1) when all the chemicals are added (Tables E-32 and E-33).

Assessment of Immediate Worker Consequences - No immediate worker consequences are calculated for NC3-C because no workers are in the Hot Cell where the event occurs.

NC3-D Dropped Drum or Canister Outside Hot Cell Accident Scenario:

NC3-D is composed of hazardous events 5CE-1 and 12E-1. Event 5CE-1 represents dropping a loaded drum carriage in the CUR while removing the carriage from a 10-160B cask. Event 12E-1 represents dropping a loaded facility canister into the Transfer Cell while being lifted in preparation for placing it in a facility cask. If it is assumed that each of these events is independent, then the frequency of the Dropped Drum or Canister Outside Hot Cell event can be assumed to be equivalent to the highest frequency of the individual events for the purposes of determining which Evaluation Guidelines apply.

Hazardous event 5CE-1 postulates dropping a five drum carriage while lifting due to the carriage getting caught and over stressing the lifting fixture or basket. The causes of this event are mechanical/ equipment failure and human error. The frequency of event 5CE-1 is a function of the number of waste drum carriages processed through the Hot Cell each year and the probability of dropping the carriage while lifting it from the 10-160B cask. The maximum number of 10-160B casks that will be processed in one year is 208. Since there are two waste drum carriages in each 10-160B cask, the total number of times a carriage will be lifted is 416 per year. From Table D-9 of the WIPP CH SAR,[6] the probability of a crane drop per lift due to all mechanisms is 3.4E-06. The frequency of event 5CE-1 is: 416 lifts/yr * 3.4E-06 = 1.4E-03/yr or "unlikely" (10^{-2}/yr $\geq$ frequency >10^{-4}/yr).

Hazardous event 12E-1 postulates dropping a loaded facility canister into the Transfer Cell. The causes of this event are equipment failure, human error, and lid failure. The frequency of event 12E-1 is a function of the number of facility canisters that are processed through the Hot Cell each year and the probability of dropping a canister into the Transfer Cell while lifting. The maximum number of 10-160B casks that will be processed in one year is 208. Since there are ten drums in each 10-160B cask, the total number drums will be processed is 2080 per year. Since a facility canister can hold three drums, a total of (2080/3 =) 693 facility canisters will be processed per year. From Table D-9 of the WIPP CH SAR,[6] the probability of a crane drop per lift (F_{Drop})due to all mechanisms is 3.4E-06. The frequency of event 12E-1 is: 693 lifts/yr * 3.4E-06 = 2.4E-03/yr or "unlikely" (10^{-2}/yr $\geq$ frequency >10^{-4}/yr).

Since both events of NC3-D have a frequency in the "unlikely" range (10^{-2}/yr $\geq$ frequency >10^{-4}/yr), The consequences of NC3-D are compared against the Evaluation Guidelines for the "unlikely" frequency range.

The release from the waste drums in the loaded facility canister is bounded by the release from a dropped waste drum carriage. Since it is assumed that all of the radiological material from an entire 10-160B cask is located in a single waste drum, assuming that ten drums are impacted is equivalent to assuming that the one drum containing all of the radiological material is damaged. Therefore, for the radiological source term analysis, it will be assumed that only one waste drum is breached by a dropping the waste drum carriage while lifting it from the 10-160B cask in the CUR, resulting in a release of the radiological material (CD = 1). The MAR for this event is 20 PE-Ci (CD x CI).

In determining the non-radiological MAR it is assumed that ten waste drums in the CUR are subject to the effects of dropping a waste drum carriage during lifting. Since this event postulates dropping a loaded waste drum carriage (containing five drums) onto the second waste drum carriage (also containing five drums), it is assumed that the non-radiological MAR is the content of ten waste drums (CD = 10). The non-radiological MAR is limited to the hazardous material content of ten waste drums or 2430 pounds.

The DR in this case is based on the amount of damage the waste drums receive as a result of the impact and how much of the contents are exposed as a result. The waste drums are DOT Type A containers. The drop in this event is from the lifting fixture on the crane during unloading operations in the CUR. The height of the drop is assumed to be greater than four feet. From section 5.2.1.1, the DR for drops greater than five feet but less than or equal to ten feet is 0.025. The DR for this event is 0.025.

Estimated Noninvolved Worker and MEI Consequences and Comparison to Risk Evaluation Guidelines - Based on the values for the source term variables as presented above, the worst-case, no-mitigation MEI and noninvolved worker consequences (Appendix E Tables E-34 and E-35) of NC3-D are well within the radiological and non-radiological risk evaluation guidelines for the unlikely range. The non-radiological results meet the guidelines (i.e., the sum of ratios < 1) when all the chemicals are added (Tables E-36 and E-37).

Assessment of Immediate Worker Consequences - No immediate worker consequences are calculated for NC3-D because no workers are in either the CUR, Hot Cell or Transfer Cell where the event occurs.

<u>NC3-E Puncture of Drum in Hot Cell Accident Scenario:</u>

NC3-E consists of hazardous event 10A-1 which postulates a puncture of a drum with the PAR manipulator caused by human error and/or equipment failure. The potential consequences of this event are: breach of drum, spread of contamination, offsite and onsite consequences, release of hazardous waste and operational down time. Breach of a drum could cause a significant release of radioactivity to the environment.

The frequency of event 10A-1 is a function of the number of waste drums handled using the PAR manipulator per year, the probability of an error by the operator while using the PAR manipulator such that the arm strikes a waste drum, and the probability that the drum is breached given that it is struck by the arm. As discussed above, 2080 waste drums will be processed through the Hot Cell each year. It is assumed in this analysis that the human error of striking a drum with the PAR manipulator arm is equivalent to the failure to follow a clear, unambiguous procedure. From Table D-1 of the WIPP CH SAR,[6] the probability of failing to correctly follow a clear, unambiguous procedure is 1E-03 per demand. Note that it is also possible that an equipment failure could result in the PAR manipulator striking the drum. However, given the extensive preventative maintenance program and requirement for pre-operational checks of the manipulator at the beginning of each shift, it is assumed that the failure is dominated by human error and the equipment failure probability is not included. ANL/EAD/TM-29[63] provides the conditional probability of drum puncture given that it is struck by equipment during handling. The probability ranges from 1.0E-02 to 2.0E-03, with one outlier probability reported as 0.25. The use of a conditional probability of waste drum failure due to being stuck by the PAR manipulator arm would be highly conservative. It is unlikely that the PAR manipulator is strong enough to actually puncture a waste drum and most events in which the arm did strike a drum would involve glancing blows. In addition, slip clutches have been provided at each joint (shoulder, elbow, and wrist) to prevent a drum from being punctured. As the robotic arm is manipulated, rotated, or extended from any orientation and contacts the drum lid, the manipulator stops the motion that the operator is directing from the control console. The operator may still have the controls engaged but the arm will not continue in the path of travel. One additional event to be considered is a strike while lowering the manipulator arm with the telescoping tube hoist. The telescoping tube hoist is lowered by cable and has a cable slack limit switch. The switch is provided to detect cable slack that may occur during full extension or when an obstruction is encountered. This precludes the hook from being forced into the drum. The smaller estimate of the probability of 2.00E-03 is divided by 2 because of the slip clutches being used. The frequency of hazardous event 10A-1 is: 2080 operations/yr * 1.0E-03 * 1.0E-03 = 2.1E-03/yr. The frequency of NC3-E is in the "unlikely" range (10^{-2}/yr ≥ frequency >10^{-4}/yr) and its consequences of NC3-E are compared against the Evaluation Guidelines for the "unlikely" frequency range.

Since this event involves puncturing a single waste drum, the CD equals 1.

Since it is assumed that all of the radiological material from an entire 10-160B cask is located in a single waste drum, the MAR is 20 PE-Ci (CD x CI). As with the radiological MAR, in determining the non-radiological MAR it is assumed that one waste drum in the Hot Cell is punctured. Therefore, it is assumed that the non-radiological MAR is the content of 1 waste drum (CD = 1). Therefore, the non-radiological MAR is limited to the hazardous material content of 1 waste drum or 243 pounds.

The waste drums are DOT Type A containers. From section 5.2.1.1, the DR for DOT Type A waste drums that are breached by impact with waste handling equipment is 0.05. The DR for this event is 0.05.

Estimated Noninvolved Worker and MEI Consequences and Comparison to Risk Evaluation Guidelines - Based on the values for the source term variables as presented above, the worst-case, no-mitigation MEI and noninvolved worker consequences (Appendix E Tables E-38 and E-39) of NC3-E are well within the radiological and non-radiological risk evaluation guidelines for the unlikely range. The non-radiological results meet the guidelines (i.e., the sum of ratios < 1) when all the chemicals are added (Tables E-40 and E-41).

Assessment of Immediate Worker Consequences - No immediate worker consequences are calculated for NC3-E because no workers are in the Hot Cell where the event occurs.

NC3-F Puncture of Drum or Canister Outside Hot Cell Accident Scenario:

NC3-F is composed of hazardous events 12E-2, 12E-3, 12E-4, and 14B-1.

Hazardous event 12E-2 postulates the Hot Cell shield valve inadvertently closing on a facility canister and shearing the canister. The causes of this event are mechanical-electrical failure or control system failure. The frequency of event 12E-2 is a function of the number of facility canisters processed through the Hot Cell in a year and the probability of spurious closure of the Hot Cell shield valve during movement of the canister. 693 facility canisters will be processed through the Hot Cell and Transfer Cell in a year. The PLG1317[38] evaluation of the probability of the shield valve closing on a waste canister is 2.00E-13 per transfer. The frequency of event 12E-2 is: 693 transfers/yr * 2.00E-13 = 1.4E-10/yr or "beyond extremely unlikely" (10^{-6}/yr ≥ frequency).

Event 12E-3 postulates inadvertent movement of the Hot Cell crane while lowering the facility canister into the Transfer Cell and damaging the canister. The causes of this event are mechanical-electrical failure, control system failure, and human error. The frequency of event 12E-3 is a function of the number of facility canisters processed through the Hot Cell in a year and the probability of spurious movement of the Hot Cell crane while the canister is being moved into the Transfer Cell and the probability that the resulting impact ruptures the canister. 693 facility canisters will be processed through the Hot Cell and Transfer Cell in a year. The spurious movement of the Hot Cell crane could be the result of either human error or equipment failure. However, EEG-74[64] indicates that 90 to 95 percent of all crane incidents are caused by operator error. For this analysis, it is assumed that the spurious movement of the crane is due to an operator error. It is also assumed that the error is equivalent to the failure to follow a clear, unambiguous procedure in operating the crane. Table D-1 of the WIPP CH SAR[6] provides a probability of 1E-03 for failure to follow a clear, unambiguous procedure. EANL/EAD/TM-29[63] provides estimates of the conditional probability of rupture of a waste drum due to impact during waste handling operations of from 1E-2 to 2E-3. Since the facility canister is more robust than a waste drum, it would be less likely to breach from an impact than a waste drum. Therefore, the lower value of 2.00E-03 is assumed to apply in this case. The frequency of event 12E-3 is: 693 transfers/yr * 1.00E-03 * 2.00E-03 = 1.4E-03/yr or "unlikely" (10^{-2}/yr $\geq$ frequency >10^{-4}/yr).

Hazardous event 12E-4 postulates inadvertent movement of the shuttle car with the facility canister partially lowered. The causes of this event are mechanical-electrical failure or shuttle car control system failure, human error and interlock failure (shuttle car is interlocked with shield valve). The frequency of event 12E-4 is a function of the number of facility canisters processed through the Hot Cell in a year and the probability of spurious movement of the shuttle car during placement of the canister. 693 facility canisters will be processed through the Hot Cell and Transfer Cell in a year. As discussed in Section 5.2.3.3, the probability of the shuttle car moving while a lift is occurring is 3.30E-12. The frequency of event 12E-4 is: 693 lifts/yr * 3.30E-12 = 2.3E-10/yr or "beyond extremely unlikely" (10^{-6}/yr $\geq$ frequency).

Hazardous event 14B-1 postulates the robotic arm breaches the facility canister during a contamination survey. The causes of this event are robotic control equipment failure. The frequency of event 14B-1 is a function of the number of facility canisters processed per year, the probability of an error by the operator while using the robotic are such that the arm strikes a facility canister, and the probability that a canister is breached when it is struck by the arm. Upon closer examination, it has been determined by the vendor[67] that the robotic arm is designed such that it is not capable of puncturing a facility canister and the drums it contains. Further analysis of this event is not required and is classified as "beyond extremely unlikely" (10^{-6}/yr $\geq$ frequency).

Since the individual events that form NC3-F has a frequency either in the "unlikely" (10^{-2}/yr $\geq$ frequency > 10^{-4}/yr), or "beyond extremely unlikely" (10^{-6}/yr $\geq$ frequency) ranges, the consequences of NC3-F are compared against the Evaluation Guidelines for "unlikely" frequency range.

As discussed previously, it is assumed that the entire 20 PE-Ci inventory is located in a single waste drum (CI = 20 PE-Ci). This event involves breaching a loaded facility canister inside the Transfer Cell. The loaded Facility canister contains three waste drums, all of which could be breached in this vent. As discussed in Section 5.2.1.1, it is assumed that all three drums breached in a facility canister each contain the maximum radiological contents of a 10-160B cask. Therefore, for this event the CD is 3 and the MAR is 60 PE-Ci (CD x CI).

To determine the non-radiological MAR, it is assumed that three waste drums in the Transfer Cell are breached. Therefore, the non-radiological MAR is the content of three waste drums (CD = 3). The non-radiological MAR is limited to the hazardous material content of three waste drums or 729 pounds.

This accident scenario involves the breaching of waste drums inside a facility canister. Only the waste drum confinement is considered for this event. The waste drums are DOT Type A containers. From section 5.2.1.1, the DR for DOT Type A waste drums breached by impact with waste handling equipment is 0.05. Therefore, the DR is 0.05 for this event.

Estimated Noninvolved Worker and MEI Consequences and Comparison to Risk Evaluation Guidelines - Based on the values for the source term variables as presented above, the worst-case, no-mitigation MEI and noninvolved worker consequences (Appendix E Tables E-42 and E-43) of NC3-F are well within the radiological and non-radiological risk evaluation guidelines for the unlikely range. The non-radiological results meet the guidelines (i.e., the sum of ratios < 1) when all the chemicals are added (Tables E-44 and E-45).

Assessment of Immediate Worker Consequences - No immediate worker consequences are calculated for NC3-F because no workers are in the Transfer Cell where the event occurs.

NC3-G Puncture of 10-160B Cask in RH Bay Accident Scenario:

NC3-G consists of hazardous event 1B-6 which postulates the puncture of a 10-160B cask by a compressed gas cylinder in the RH Bay. The causes of this event are human error and gas cylinder failure. Spontaneous failure of a gas cylinder in the RH Bay such that it becomes a missile and strikes a 10-160B cask is considered to be incredible based on the limited number of cylinders (only two cylinders are in the RH Bay) and the general margin of safety in the design of the cylinders. However, if the cylinders are dropped during movement, it is possible for failure to occur such that the cylinders would become missiles. Procedural limits are placed on the movement of compressed gas cylinders in the RH Bay. The gas cylinders are not moved while RH cask operations are occurring in the RH Bay. Therefore, it would require operator error to fail to follow procedures for movement of the cylinders to occur while a 10-160B cask is in the RH Bay. Furthermore, it would also require failure of a checker to identify that the procedure is being violated. From Table D-1 of the WIPP CH SAR[6], the human error probability to accomplish a clear unambiguous task is 1.0E-03 and the failure of a checker to identify the error is 1.0E-01 per demand. The combination of the two is the probability of a gas cylinder movement (operator error) with a 10-160B cask is in the RH Bay.

There are two full gas cylinders in the RH Bay at a time, it is assumed that the cylinders will be changed out four times per year, there would be eight cylinders available for this event to occur. For conservatism, sixteen cylinders are assumed to be moved in the RH Bay in a year. Therefore, it is conservatively assumed there are sixteen chances for the cylinders to be moved in violation of procedure per year. Additionally, even with the violation of procedure and movement of the cylinders, an error resulting in dropping of a cylinder, failure of the cylinder on impact, and the cylinder becoming a projectile and striking a 10-160B cask with sufficient force to damage the DOT Type A drums inside would have to occur. Each of these is examined to produce an estimate of the frequency of the event. For the gas cylinders to fall and become a missile, safe handling procedures must be violated (safety cap not installed, cylinder cart not used, etc.) and the cylinder valve strike a surface and shear off. It is conservatively assumed that this sequence of events has a conditional probability of 0.2. Because of the round shape and robustness of the Type B road cask, the missile must make a head-on strike on the cask. Ignoring the vertical dimension, the probability of the random direction of the gas cylinder impacting the cask head on is conservatively estimated as 5/360 = 1.4E-02.

The 10-160B cask is a certified Type B shipping cask and is designed to withstand vehicle crashes, fires and other transportation hazards. The 10-160B cask SAR[66] contains (puncture test) analysis considering only the outer two inch thick carbon steel wall, which shows the 72,000 lbs loaded cask can withstand a forty inch side drop onto a six inch diameter mild steel bar without significant damage. The maximum loading on the cask outer wall is based on the properties of the six inch diameter mild steel bar ($1.26x10^{6}$ lbs). The calculated stress due to bending is 1,613 psi which is less than the 48,000 psi allowable. In addition, the cask wall also contains 1-7/8 inches of lead and an inner wall of 1-1/8 carbon steel. If the cask composite wall was breached, the type A drum would also have to be breached inside of the cask. Based on this a conditional probability for a drum inside the cask to be breached and release its contents is conservatively taken as 0.01. The frequency of hazardous event 1B-6 is: 16 demands/yr * 1.0E-03 * 0.1 * 0.2 * 1.4E-02 * 1E-02 = 4.4 E-08/ yr or "beyond extremely unlikely" (10^{-6}/yr $\geq$ frequency). There are no guideline limits for this frequency.

Estimated Noninvolved Worker and MEI Consequences and Comparison to Risk Evaluation Guidelines - The worst-case, no-mitigation MEI and noninvolved worker consequences of NC3-G are well within the radiological (Appendix E Tables E-46 and E-47) and non-radiological (Tables E-49 and E-50) risk evaluation guidelines for the extremely unlikely range.

Assessment of Immediate Worker Consequences - No current risk evaluation guidelines exist for the assessment of accident consequences to immediate workers. Therefore, in the absence of guidelines, and for conservatism, the noninvolved worker radiological and non-radiological guidelines for the extremely unlikely range are used as a reference point for the assessment of consequences to immediate workers and the evaluation of the adequacy of the WIPP defense-in-depth features. The worst-case consequences to the immediate worker from NC3-G (Appendix E Tables E-48 and E-51) are well within the risk evaluation guidelines. Therefore, no specific additional worker protection engineering or administrative controls beyond those already qualitatively identified as providing defense-in-depth for the immediate worker, are needed based on the quantitative consequence assessment results.

NC3-H Dropped 10-160B Cask in RH Bay Accident Scenario:

NC3-H consists of hazardous event 4D-1 which postulates the 10-160B cask, with loosened lid bolts, falling off the road cask transfer cart (RCTC) in the RH Bay while the cask is being transferred to the CUR. The potential consequences of this event are: loss of production (CH and RH), breach of drums, direct radiological exposure to facility worker, on-site and off-site consequences, spread of contamination, release of hazardous material, facility and equipment damage. Breach of a 10-160B cask and drums could cause a significant release of radioactivity to the environment.

Mechanisms for causing this to occur include derailment of the RCTC during movement, impact of the RCTC by a vehicle in the RH Bay, and impact with the CUR shield door separating the RH Bay from the CUR. Derailment of the RCTC during movement could be the result of either a foreign object on the rails or failure to replace the removable rails at the entrance to the CUR. Analysis[68] has conservatively shown that the event is not a credible as long as vehicles that do not exceed the limits of tables contained in the analysis are not allowed in RH Bay when a 10-160B cask head bolts are removed. The NC3-H event is not a credible event and has a frequency in the "Beyond Extremely Unlikely" range (10^{-6}/yr $\geq$ frequency).

The loaded 10-160B cask contains ten waste drums. All ten of the waste drums could potentially be damaged. However, the waste drums are DOT Type A containers and will withstand a drop of four feet with no damage. Given the height of the 10-160B cask is only slightly more than seven feet[11] and even with the cask falling from an RCTC only the top drum carriage in the cask would experience the equivalent of a drop in excess of four feet. It is assumed that only five waste drums are impacted by this event. Since it is assumed that all of the radiological material from a 10-160B cask is located in a single waste drum, the five drums impacted is equivalent to assuming the one drum containing all of the radiological material is damaged. Therefore, for the radiological source term analysis, it will be assumed that only one waste drum is breached by the road cask falling over in the RH bay, resulting in a release of the radiological material (CD = 1). The MAR is 20 PE-Ci (CD x CI) for this event.

As with the radiological MAR, in determining the non-radiological MAR it is assumed that five waste drums are subject to the effects of the road cask falling over during movement. Therefore, it is assumed that the non-radiological MAR is the content of five waste drums (CD = 5) or 1215 pounds.

The DR is determined based on the amount of damage the waste drum receives as a result of the impact and how much of the contents are exposed as a result. Since the drop could be greater than four feet in height, it is possible for the waste drums to be damaged. From section 5.2.1.1, the DR for drops of waste containers from the heights greater than five feet but less than or equal to ten feet is 0.025. The DR for this event is 0.025.

Estimated Noninvolved Worker and MEI Consequences and Comparison to Risk Evaluation Guidelines - Based on the values for the source term variables as presented above, the worst-case, no-mitigation MEI and noninvolved worker consequences of NC3-H are well within the radiological (Appendix E Tables E-52 and E-53) and non-radiological (Tables E-55 and E-56) risk evaluation guidelines for the extremely unlikely range.

Assessment of Immediate Worker Consequences - No current risk evaluation guidelines exist for the assessment of accident consequences to immediate workers. Therefore, in the absence of guidelines, and for conservatism, the noninvolved worker radiological and non-radiological guidelines for the extremely unlikely range are used as a reference point for the assessment of consequences to immediate workers and the evaluation of the adequacy of the WIPP defense-in-depth features. The worst-case consequences to the immediate worker from NC3-H (Appendix E Tables E-54 and E-57) are well within the risk evaluation guidelines. Therefore, no specific additional worker protection engineering or administrative controls beyond those already qualitatively identified as providing defense-in-depth for the immediate worker, are needed based on the quantitative consequence assessment results.

NC3-I Toxic Gas Generation in Hot Cell Accident Scenario:

At the time the 10-160B HAZOP[56] was performed, the facility canister design required the lid to be welded to the canister body. The canister design was changed so that the lid mechanically locks to the canister body and welding is no longer performed. Hazardous event 11D-3 postulated that ultraviolet light from the welding activity caused the head space gases in the facility canister to be converted into phosgene gas (toxic) which is released into the Hot Cell. Since welding is no longer performed, no further analysis will be performed on the scenario.

NC3-Safety Structures, Systems, and Components

Based on the source term analysis for this accident, Safety Class or Safety Significant SSCs are not required. The following input data and assumptions are used in the frequency and source term analyses:

- The radiological inventory of a 10-160B cask is limited to 20 PE-Ci.
- The hazardous chemical inventory in the RH waste is the same as for the CH waste.
- The maximum loading of an RH waste drum is 243 lbs of hazardous material.

- A worker involved in a waste-handling accident will stop the operations, examine the cask or drums and determine a breach has occurred, and begin to exit the immediate area within 30 seconds of a waste handling accident occurring..
- A 10-160B cask can contain no more than 10 waste drums.
- The waste drums in a 10-160B cask are DOT Type A (or equivalent) 55 gallon drums.
- No more than two 10-160B casks will be in the RH Bay at one time.
- The RH Bay doors are closed at all times during waste handling activities related to the 10-160B cask inside the bay.
- The CUR shield door is closed during the removal of cask lid or the drums from the cask.
- No more than six fully loaded facility canisters are stored in the Hot Cell.
- Only one partially loaded facility canister is stored in the Hot Cell.
- Only ten waste drums can be stored in the Hot Cell and not in a facility canister. All other waste drums in the Hot Cell are in facility canisters.
- An extended period of time between placing the lid on a fully loaded facility canister and sealing the lid is not allowed to occur.
- The maximum height a waste drum or Facility canister can be dropped in the Hot Cell is 10 ft.
- The air movement rate through the RH Bay cask receiving area is 0.25 m/second.

The defense-in-depth SSCs which are applicable to the above ground LOC scenarios, per the criteria in Section 3.1.3 are assigned as follows:

- DOT Type A waste drums - primary confinement
- WHB Ventilation System - secondary confinement
- Hot Cell - secondary confinement

5.2.3.13 NC4 Loss of Confinement in the Transfer Cell or Underground

Scenario Description - The 10-160B HAZOP[56] refers to the hazard analysis for 72B cask for operations that occur in the Transfer Cell (hazardous events 13ABCD-1 and 14ACDEFGHI-1) and underground (hazardous events 15ABC-1, 16ABCD-1 and 17ABCD-1) during the processing of 10-160B casks. At the point in processing of a 10-160B cask where these events are postulated to occur, the waste drums from the 10-160B cask have been loaded into a facility canister, which is being or has been loaded into a facility cask for disposal.

The potential consequences of the LOC in the Transfer Cell and LOC underground events are not explicitly analyzed in the 10-160B HAZOP[56] because of the following:

- Processing a facility canister or a 72B waste canister in the Transfer Cell until emplacement in the borehole in the Underground is the same.
- The radiological content of a 72B waste canister (80 PE-Ci minimum) bounds the radiological content of a facility canister (60 PE-Ci max).

- The potential consequences identified for the 72B cask processing (RH3, RH4-A, and RH4-B) apply to the 10-160B cask processing.
- The potential consequences of a LOC in the Transfer Cell and a LOC underground for the waste drums from a 10-160B are significant radioactive materials release.

Preventive and Mitigative Features - General preventive and mitigative measures identified in the HAZOP[56] for this specific scenario are listed in Table 5.1-10.

Estimated Frequency - The 10-160B HAZOP[56] does not rank the frequency of the NC4. The Transfer Cell and underground processing of a facility canister is equivalent to processing a 72B canister with frequencies identified in RH3, RH4-A and RH4-B. The scenario frequencies developed for the events in the 72B canister processing are applicable to the facility canister processing.

Loss of Confinement in the Transfer Cell

The frequency of the LOC in the Transfer Cell accident (13ABCD-1 and 14ACDEFGHI-1) is the same as RH3 which has been determined to be in the "beyond extremely unlikely" frequency bin (10^{-6}/yr $\geq$ frequency).

Loss of Confinement Underground

LOC in the underground has been broken down into two events: LOC due to waste hoist failure (15ABCD-1) and LOC occurring during waste movement (16ABCD-1 and 17ABCD-1). The frequency of the LOC due to waste hoist failure is the same as RH4-A and has been determined to be in the "beyond extremely unlikely" frequency bin (10^{-6}/yr $\geq$ frequency), while the frequency of the LOC underground (waste movement) accident is the same as RH4-B and has been determined to be in the "unlikely" frequency bin (10^{-2}/yr $\geq$ frequency > 10^{-4}/yr).

Source Term Development - The source terms developed for the 72B canister RH3, RH4-A, and RH4-B accidents are applicable to the 10-160B cask operations.

Estimated Noninvolved Worker and MEI Consequences and Comparison to Risk Evaluation Guidelines - The consequence analysis terms developed for the RH3, RH4-A, and RH4-B accidents are applicable to facility canister operations. 10-160B accident consequence analysis is bounded by the 72B consequence analysis and a separate consequence analysis is not developed.

Assessment of Immediate Worker Consequences - No specific consequence analysis is performed for NC4 because the consequence analysis terms developed for the RH3 and RH4-B accidents are applicable to the facility canister operations. There is no Immediate Worker in the Transfer Cell and since the immediate worker consequence analysis developed for the RH4-B bounds the 10-160B accident consequence analysis, a separate immediate worker consequence analysis is not developed.

Safety Structures, Systems, and Components - The source terms developed for the 72B canister for RH3, RH4-A, and RH4-B accidents are applicable to the 10-160B cask operations. The data and assumptions developed in the 72B canister RH3, RH4-A, and RH4-B accidents are applicable to the 10-160B cask operations.

The defense-in-depth SSCs which are applicable to this scenario, per the criteria in Chapter 3, Section 3.1.3 are assigned as follows:

- Vented DOT Type A waste drum - Primary Confinement
- Facility canister - Secondary Confinement
- WHB Ventilation System - Tertiary Confinement
- Facility cask - Tertiary Confinement
- Transfer Cell - Tertiary Confinement
- Underground Ventilation System - Tertiary Confinement

5.2.3.14 NC5 Explosion Followed by Fire in the Hot Cell

Scenario Description - The HAZOP[56] for the 10-160B cask operations postulated a waste drum breach from an explosion and a subsequent fire in the Hot Cell. The HAZOP[56] postulated two hazardous events (9-2 and 11D-2) that could result in a explosion and a subsequent fire in the Hot Cell which could cause a significant release of radioactivity.

Hazardous event 9-2 postulated an explosion and a subsequent fire in the Hot Cell which could breach a drum or multiple drums. The fire or explosion is postulated to occur at the point in the process when the waste drums have been removed from the 10-160B cask and are placed in the Hot Cell for processing and storage until they are placed in a facility canister. The possible cause of the explosion is ignition (metal to metal contact causes a spark) of flammable gas generated in the drum.

At the time the 10-160B HAZOP[56] was performed, the design of the facility canister required the lid to be welded to the canister body. The canister design was changed so that the lid mechanically locks to the canister body and welding is no longer performed. Hazardous event 11D-2 postulated an explosion in the Hot Cell which could breach a drum releasing contamination. The explosion is postulated to occur during the welding of facility canister lid to the canister body by a robotic welder. The possible cause of the explosion is ignition of flammable headspace gases in the facility canister during welding. Since welding will not occur in the Hot Cell, this event is not developed.

Preventive and Mitigative Features - General preventive and mitigative measures identified in the HAZOP[56] process for this specific scenario are listed in Table 5.1-10.

Estimated Frequency - The HAZOP Team qualitatively estimated the frequency of occurrence of an explosion followed by fire in the Hot Cell to be in the anticipated range ($10^{-1} \geq$ frequency$>10^{-2}$). The frequency of hazardous event 9-2 is not calculated because a spark induced explosion can not occur in the Hot Cell for the following reasons:

- 10-160B waste drum are packaged to WAC requirements. The WAC does not allow flammable items in waste drums and limits the gas generation rate on the waste in the drums.
- 10-160B waste drums are vented Type A drums. The vent filters will allow gases within the drum to escape into the Hot Cell volume where the Hot Cell ventilation flow, which has a higher flow rate than the drum’s gas generation rate, will quickly diffuse and dilute the flammable gases such that if a spark did occur, the required fuel/ air mixture to initiate an explosion or ignite a fire would not be present.

- During waste processing in the Hot Cell, any sparks generated from the waste handling equipment and a drum (metal to metal contact) would occur external to the drum and would not have the energy to penetrate the drum lid or vent filter to ignite the flammable gases in the drum headspace. If the vent filter was not present, then flammable drum gases would not accumulate.

Source Term Development - Considering hazardous event 9-2 cannot occur there will be no release of radioactivity.

5.2.3.15 NC6 Fire Followed by Explosion in the Underground

According to Section 5.2.3.6 (RH5), the fire followed by explosion in the underground that causes a release of hazardous materials from the facility cask or from a 72B canister is not credible. Therefore, a fire followed by explosion during processing of the waste from a 10-160B cask in the facility cask or facility canister would not cause a release of hazardous materials. The design features and controls credited in RH5 will be applicable to the processing of 10-160B cask waste.

5.2.3.16 NC7 Seismic Event

Scenario Description - The HAZOP[56] for the 10-160B RH operations postulated a LOC in the RH Bay due to a seismic event (20-1) that could lead to a breach of a drum or multiple drums. Hazardous event 20-1 postulates a seismic event that occurs during the period of time that the 10-160B cask lid is loose that causes a breach of one or more waste drums.

The HAZOP[56] for the 10-160B RH operations also postulated a full facility fire that involves the Hot Cell or other RH facilities and which could cause a breach of one or more waste drums. Hazardous event 20-2 postulates a full facility fire that causes the breach of one or more waste drums. The possible cause of the fire is an earthquake.

Preventative and Mitigative Features - General preventative and mitigative measures identified in the HAZOP process for this specific scenario are listed in Table 5.1-10.

Estimated Frequency - The HAZOP[56] for 10-160B RH operations ranked the frequency of a DBE event as "unlikely" (10^{-2}/yr $\geq$ frequency > 10^{-4}/yr). The DBE is based on a 1,000 year return interval. The frequency of the DBE event is 1E-3 per year and the frequency bin is "unlikely".

The HAZOP[56] ranked the likelihood of the hazardous event Full Facility Fire as "unlikely" (10^{-2}/yr $\geq$ frequency > 10^{-4}/yr). However, this event postulates a fire involving the entire RH facility resulting from a DBE. The conditional probability of a fire resulting from the DBE ranges from about 3E-02 to 3E-03, depending on the specific structure design and the intensity of the seismic event[57]. The frequency of a fire resulting from a DBE is in the range of 3E-05 to 3E-06 per year or the "extremely unlikely" range (10^{-4}/yr $\geq$frequency.> 10^{-6}/yr).

Additionally, the waste may be in several areas of the RH facility at the time of the earthquake and fire. The RH bay can contain up to two 10-160B casks. The WHB and the RH bay crane are seismically qualified to survive a DBE. Therefore, the 10-160B casks in the RH bay would not be damaged by falling structures. The 10-160B casks should remain intact during any realistic fire that resulted from the DBE. The waste drums in the road casks would be protected from the effects of a fire that resulted from the DBE as long as the cask was intact and sealed. The drums would only be at risk from the fire during the period of time the cask is being transferred to the CUR by the RCTC with its lid un-bolted. The DBE could dislodge the un-bolted lid and expose the drums to the effects of a seismically induced fire.

However, for this scenario to occur, the seismic event would have to happen only during the time period when the 10-160B cask is being transferred with the lid un-bolted. Even with the lid un-bolted, the cask would still limit the impact of the fire on the waste drums. Based on these facts, the scenario of a DBE caused fire occurring during the time period the 10-160B cask lid is un-bolted and results in the release of hazardous material is considered incredible.

Waste drums may also be present in the Transfer Cell in a facility canister. However, a facility canister would also protect these drums from the effect of a fire and the Transfer Cell is qualified to withstand a DBE. The Hot Cell is also DBE qualified. The only way in which a fire could involve a larger material at risk than that analyzed for the previous events would be for a fire to originate in one area (the RH Bay, the CUR, the Hot Cell, or the Transfer Cell) and then propagate to another area. The design of the WHB and the operation of the RH system makes this highly unlikely. The RH Bay is separated from the CUR by a steel door that is closed if a 10-160B is in the CUR. This door would prevent a fire from spreading from the RH Bay to the CUR and vice versa. Secondly, the CUR is separated from the Hot Cell by shield plugs and thick concrete walls. If the shield plug is not in place, procedures require the CUR door to be closed. Due to its construction, a fire originating in the Hot Cell could not propagate to the RH Bay through the CUR and vice versa. Finally, the Transfer Cell and Hot Cell are separated by a shield valve that is opened only when a facility canister is being lowered into the Transfer Cell. Once a facility canister is loaded in the shuttle car, the shield valve is closed. A fire originating in the Transfer Cell would not propagate to the Hot Cell and vice versa. Based on these facts, it is incredible for a fire to involve multiple areas of the RH system.

Source Term Development - A DBE that results in a full facility fire is incredible and a source term is not developed. A DBE that results in a fire in the RH Bay during transfer of a 10-160B cask to the CUR is also considered to be incredible and a source term is not developed. A DBE by itself has limited potential to result in the release of hazardous material. This assessment of the potential releases is based on the following facts:

- The WHB including the RH Bay, the Hot Cell, and Transfer Cell is DBE qualified [58]. The WHB and its structures and equipment will not fail during a DBE and impact a 10-160B cask, waste drums, or a facility canister.
- The 140/25-ton crane in the RH Bay is DBE qualified. The crane will not fail during a DBE and impact a 10-160B cask in the RH Bay nor will it drop a load onto the cask.
- The Hot Cell crane and the PAR Manipulator are DBE qualified . The Hot Cell crane and PAR Manipulator will not fail or drop a load during a DBE and impact a 10-160B cask, waste drum or facility canister.
- The Transfer Cell Shuttle Car is DBE qualified. The Transfer Cell Shuttle Car will not drop or otherwise impact the integrity of a facility canister in the Transfer Cell during a DBE.
- Fires starting in the Support Building, the WHB, or Building 412 has the potential to destroy the entire structure. This potential fire was analyzed in the FHA[48] and the frequency was found to be beyond extremely unlikely. The potential for a full facility fire is very low due to the low combustible loading in the WHB, the combustible material control program, and relatively few ignition sources.

Based on the above information and a review of the processing steps involved in 10-160B operations, the most vulnerable step in the process from the standpoint of the release of hazardous material due to a DBE is during movement of the 10-160B from the RH Bay into the CUR. During this process, the 10-160B is on the RCTC with its lid un-bolted but still in place. A DBE occurring at this point in the process could dislodge the 10-160B cask lid such that it impacts and damages the waste drums inside.

Figure 4.2-5 provides the general layout of the 10-160B cask. The cask lid is attached by bolts to the top of the 5.5 inch thick outer wall and is the same diameter as the outer dimensions of the cask wall. The cask lid has a three inch thickness inside the cask that mates up with the inner wall of the cask. For the unbolted cask lid to slide during a DBE, the kinetic energy imparted to lid would have to lift the 7,450 lb lid three inches. Additionally, two lift lugs are located 180 degrees from each other with a one inch side clearance to the lid and act to inhibit lid motion during a seismic event. In the event the cask lid was lifted up and could slide on top of the cask, the larger diameter of the cask lid would preclude the lid from falling in on the waste drums inside the cask.

Further assurance that the event is incredible is obtained by examining the magnitude of the DBE. As discussed in Section 2.5.5, the geologic and seismic assumptions leading to the 1000 year peak acceleration include the consideration of a Richter magnitude 5.5 earthquake at the site, a 6.0 magnitude earthquake on the Central Basin Platform, and a 7.8 magnitude earthquake in the Basin and Range subregion. These magnitudes correspond roughly to equivalent epicentral intensity events of VII, VIII and XI on the Modified Mercalli Intensity scale[69]. These values, especially the first two, are considered quite conservative, and the other parameters used in the 0.075g derivation are also very conservatively chosen. For additional conservatism, a peak design acceleration of 0.1g is selected for the WIPP facility DBE. Bolt[69] correlates average peak acceleration to the Modified Mercalli intensity scale level. The acceleration of 0.1g corresponds to the average peak acceleration range of 0.1 - 0.15g range for Modified Mercalli Intensity scale[69] value of VII.

Table 2.5-2 provides the following description for the Modified Mercalli Intensity Scale[69] Value of VII. Because of the weight and configuration of the lid, the unbolted lid would act as an integral part of the 10-160B cask and would not slide off the cask at this earthquake intensity. Therefore, the event is considered to be incredible.

No hazardous material is postulated to be released during a DBE because to the design features described above, therefore, no source term is developed.

Estimated Consequence and Comparison to Risk Evaluation Guidelines - No hazardous material is postulated to be released during the DBE, therefore, no consequence analysis is developed.

Safety Structures, Systems, and Components - No hazardous material is postulated to be released during the DBE, therefore, Safety Class or Safety Significant SSCs are not required. The defense-in-depth SSC applicable to the NC7 scenario, per the criteria in Section 3.1.3 is the DOT Type A waste drums, Primary Confinement.

5.2.3.17 NC8 Tornado Event

Scenario Description - The HAZOP[56] postulated a LOC in the RH Bay due to a tornado that could lead to a breach of a drum or multiple drums. Hazardous event 20-3 postulates a tornado that occurs during the period of time that the 10-160B cask lid is loose that causes a breach of one or more waste drums.

The potential consequences of the tornado event are: breach of drums due to loose cask lid in RH Bay, onsite/offsite consequences, facility worker exposure, disruption of processing operations, loss of site utilities, worker injury or fatality, fire, explosion, breach of drums in Hot Cell.

Preventative and Mitigative Features - General preventative and mitigative measures identified in the HAZOP for this specific scenario are listed in Table 5.1-10.

Estimated Frequency - The HAZOP[56] ranked the frequency of a design basis tornado (DBT) event as "anticipated"($10^{-1} \geq f > 10^{-2}$). However, the DBT is based on a 1,000,000 year return interval, making the frequency of the DBT event 1 x 10^{-6} per year and the frequency bin of "extremely unlikely" (10^{-4}/yr $\geq f > 10^{-6}$/yr).

Source Term Development - A DBT event has limited potential to result in the release of hazardous material. This assessment of the potential releases is based on the following facts:

- The WHB, including the RH Bay and transfer complex (CUR, Hot Cell, Transfer Cell, and Facility Cask Loading room), is DBT qualified.[58] Therefore, the WHB and its tornado doors will protect the equipment and structures inside the WHB from the effects of a tornado that could potentially result in release of hazardous material.
- All tornado doors are closed at all times when RH waste is present in RH side of WHB.
- The 10-160B cask is DOT Type B qualified. Therefore, the 10-160B cask will withstand the effects of high wind and missiles generated by a tornado without the release of the contained material.

Based on the above information and a review of the processing steps involved in 10-160B operations, there is no identified, credible scenario in which the waste drums from a 10-160B cask are vulnerable to damage and the release of radiological or hazardous chemical material. Therefore, since no hazardous material is postulated to be released as the result of a DBT event, source term development and analysis is not required.

Estimated Noninvolved Worker and MEI Consequences and Comparison to Risk Evaluation Guidelines - No hazardous material is postulated to be released as the result of the DBT, therefore, consequence analysis is not required.

Assessment of Immediate Worker Consequences - No hazardous material is postulated to be released as the result of the DBT, therefore, consequence analysis is not required.

Safety, Structures, Systems, and Components - No hazardous material is postulated to be releases during the DBT, therefore, Safety Class or Safety Significant SSCs are not required. The following input data and assumptions are used in the analysis:

- All tornado doors are closed at all times when RH waste is present in RH side of WHB.
- The WHB is DBT qualified.
- The Hot Cell is DBT qualified.

The defense-in-depth SSCs which are applicable to this scenario, per the criteria provided in Section 3.1.3 are assigned as follows:

- DOT Type A Waste Drums - Primary Confinement
- DOT Type B 10-160B cask - Secondary Confinement
- WHB structure (includes the structure and structural components including the cranes and grapple hoist used for RH waste handling) designed to prevent failure during a DBT resulting in loss of secondary confinement

5.2.4 Assessment of WIPP RH Facility Design Basis and Waste Acceptance Criteria

5.2.4.1 Assessment of WIPP RH Facility Design Basis

As shown in Section 5.2.3, the quantitative frequency analysis for each operational accident produced the following grouping of accidents:

Anticipated Range (10^{-1}/year $\geq$ frequency>10^{-2}/year)

RH2, Fire in the WHB (hydraulic fire in the Facility Cask Loading room

Unlikely Range (10^{-2}/year $\geq$ frequency>10^{-4}/year)

RH4-B, LOC in the Underground (waste movement)

NC3-A, LOC in the WHB (dropped object on waste material in Hot Cell)

NC3-B, LOC in the WHB (dropped object on waste material outside Hot Cell)

NC3-C, LOC in the WHB (dropped drum or facility canister in Hot Cell)

NC3-D, LOC in the WHB (dropped drum or facility canister outside Hot Cell)

NC3-E, LOC in the WHB (puncture of drum in Hot Cell)

NC3-F, (hazardous event 12E-3) LOC in the WHB (puncture of drum or facility canister outside Hot Cell)

NC4, LOC in the Underground (waste movement)(same as and bounded by RH4-B)

Extremely Unlikely Range (10^{-4}/year $\geq$ frequency >10^{-6}/year)

NC1, Fire in the Hot Cell

Beyond Extremely Unlikely Range (10^{-6}/year $\geq$ frequency)

RH1, Fire in the Underground

RH3, LOC in the WHB

RH4-A, LOC in the Underground (waste hoist failure)

RH5, Fire Followed by Explosion in the Underground

NC2, Fire in the Underground (same as and bounded by RH1)

NC3-C, (hazardous events 10B-1) LOC in the WHB (dropped drum or canister in Hot Cell)

NC3-F, (hazardous events 12E-2, 12E-4 and 14B-1) LOC in the WHB (puncture of drum or canister outside Hot Cell)

NC3-G, LOC in the WHB (puncture of 10-160B cask in RH Bay)

NC3-H, LOC in the WHB (dropped 10-160B cask in RH Bay)

NC4, LOC in the Transfer Cell or Underground (waste hoist failure and Transfer Cell)(same as and bounded by RH3 and RH4-A)

NC6, Fire followed by explosion in the Underground (same as and bounded by RH5)

Releases of hazardous material as the result of accidents NC2 and NC6 were found to be incredible for 10-160B cask processing as long as the inputs and assumptions determined to be applicable to these events in the 72B RH accident analysis are maintained for the 10-160B cask processing. Releases of hazardous material as the result of accident NC8 were found to be incredible for 10-160B cask processing as long as the inputs and assumptions listed in Section 5.3 are maintained.

For all accidents, the quantitative frequency analysis has verified that the qualitative frequency ranges assigned for these scenarios in the HAZOP were either correctly or conservatively assigned.

Additional quantitative frequency analyses in the form of event/fault tree analyses were performed to identify SSCs, or processes that contribute most to the accident phenomena frequency for the purposes of verifying their adequacy or identifying improvements to reduce the accident frequency and therefore risk to immediate workers (as well as noninvolved worker and MEI). Specific accidents evaluated in this manner were: RH3, RH4A, RH4B, RH6, RH7, NC1, NC3 (A-G), and NC5. With the exceptions of RH4B, RH6, NC1, and NC3(A - F), the event tree/fault tree analyses indicated that the no-mitigation frequency of the identified accidents occurring are beyond extremely unlikely (frequency ≤ 1E-06/yr).

Accident Analysis Consequence Results

Based on the 72-B cask RH accident source term and release mechanism analyses presented in Section 5.2.3, for worst-case scenarios with a frequency greater than 1E-06/yr, the calculated worst-case no-mitigation accident consequences to the noninvolved worker and MEI, were found to be well below the selected accident risk evaluation guidelines for the unlikely range and for the immediate worker below the guidelines for the extremely unlikely range. The highest consequences are obtained from RH4-B (Table E-8 of Appendix E), with an estimated 0.6 rem (6 mSv) to the noninvolved worker (approximately 2 percent of 25 rem (250 mSv) guideline), 0.05 rem (.5 mSv) to the MEI (approximately 0.7 percent of 6.5 rem (65 mSv) guideline), and (Table E-14 of Appendix E) 5.4 rem (54 mSv), (approximately 5 percent of 100 rem (1 Sv) guideline) to the immediate worker.

Based on the 10-160B cask processing accident source term and release mechanism analyses presented in Section 5.2.3, for worst-case scenarios with a frequency greater than 1E-06/yr and for which the release of hazardous material was credible, the calculated worst-case no-mitigation accident consequences to the noninvolved worker and MEI, and immediate worker were found to be well below the selected accident risk evaluation guidelines for the appropriate frequency range. The highest consequences are obtained from NC1 (Table E-19 of Appendix E), with an estimated 8.2 rem (82 mSv) to the noninvolved worker (approximately 8 percent of the 100 rem (1 Sv) guideline) and 0.65 rem

(6.5 mSv) to the MEI (approximately 3 percent of the 25 rem (250 mSv) guideline). The highest consequences to the immediate worker are obtained from NC3-G, and NC3-H (Table E-48 and E-49 respectively) with an estimated immediate worker consequence of 4.13 rem (41.3 mSv), (approximately 17 percent of the 25 rem (250 mSv) guideline)

It should be noted that the MEI unmitigated consequences for credible, worst-case scenarios with a frequency greater than 1E-06/yr (NC1, NC3), is about 1.3 times the 500 mrem (5 mSv) temporary annual dose limit for normal operations derived from DOE Order 5400.5, and (2) the noninvolved worker consequences are about 1.5 times the 5 rem (50 mSv) annual dose limit for workers for normal operations.

No current risk evaluation guidelines exist for the assessment of accident consequences to immediate workers. Therefore, in the absence of guidelines, and for conservatism, the noninvolved worker radiological guidelines were used as a reference point for the assessment of consequences to immediate workers and the evaluation of the adequacy of the WIPP defense-in-depth features. The consequences to the immediate worker from NC3-G and NC3-H are also well within the on-site risk evaluation guidelines. Therefore, no specific additional worker protection, engineering, or administrative controls (such as respiratory protection, more stringent maximum waste canister inventory, or additional 10-160B cask WAC controls such as immobilization) beyond those already qualitatively identified as providing defense-in-depth for the immediate worker, are needed based on the quantitative consequence assessment results.

For credible scenarios with a frequency less than 1E-06/yr, the calculated unmitigated accident consequences to the noninvolved worker, and MEI were also found to be below the selected accident risk evaluation guidelines. The highest consequences are obtained from NC3-F (Table E-43 of Appendix E), with an estimated 2.47 rem (24.7 mSv) to the noninvolved worker (approximately 2 percent of the 100 rem (1 Sv) guideline) and 0.19 rem (1.9 mSv) to the MEI (less than 1 percent of 25 rem (250 mSv) guideline). No immediate worker in the Hot Cell.

It should be noted that the MEI no-mitigation consequences for all 10-160B waste handling accidents analyzed, regardless of frequency, were found to be below 25 rem (250 mSv) risk evaluation guideline. The worst-case for the 10-160B analysis calculated dose to an immediate worker is from NC3-G and NC3-H with an estimated 4.13 rem (41.3 mSv). This immediate worker dose is well below the on-site risk evaluation guidelines for the unlikely range.

For the 72-B cask, the MEI unmitigated consequences for worst-case scenarios with a frequency greater than 1E-06/yr (RH4-B), is about 11 percent of 500 mrem (5 mSv) temporary annual dose limit for normal operations derived from DOE Order 5400.5, and (2) the noninvolved worker consequences are about twelve percent of the 5 rem (50 mSv) annual dose limit for workers for normal operations.

The worst-case 72-B cask consequences to the immediate worker from RH4-A are estimated to be 116 rem (1.6Sv). No current risk evaluation guidelines exist for the assessment of accident consequences to immediate workers. Therefore, in the absence of guidelines, and for conservatism, the noninvolved worker radiological guidelines for the extremely unlikely rang were used as a reference point for the assessment of consequences to immediate workers and the evaluation of the adequacy of the WIPP defense-in-depth features. The consequences to the immediate worker from RH4-A exceed the site risk evaluation guidelines. For protection of the immediate worker, the waste hoist brake system is designated Safety Significant and specific Administrative controls are derived in Chapter 6 and assigned in Attachment 1, Preliminary Technical Safety Requirements. The risk associated with this potential exposure is deemed acceptable for the following reasons:

- The conservatism in the risk evaluation guidelines as discussed in Section 5.2.2, as well as the application of the on-site guidelines to the immediate worker,
- The very low frequency of this scenario, primarily due to the design changes which significantly enhance the system safety and reliability. As identified in EEG-59,[43] the performance of preoperational tests are of paramount importance to system reliability (for the waste hoist, as well as other WIPP SSCs), and as such, is a primary element of the first layer of WIPP defense-in-depth. Section 8.3.3.5 discusses the elements of preoperational checks as required by the conduct of operations program, and a TSR AC is derived in Chapter 6 for inclusion in the WIPP Technical Safety Requirements,
- The conservatism inherent in all of the accident analysis source term variables used to estimate the above consequences,
- The existing elements for protection of the worker discussed in detail in Section 5.1.7.

It should be noted that the MEI (exclusive use area) no-mitigation consequences for all 72B waste handling accidents analyzed, regardless of frequency, were found to be well below 25 rem (250 mSv) risk evaluation guideline.

For 72-B cask scenarios, resulting in a release, with a frequency less than 1E-06/yr (RH3, RH4-A, RH5), the calculated unmitigated accident consequences to the noninvolved worker, and MEI were also found to be below the selected accident risk evaluation guidelines. The highest consequences are obtained from RH3, with an estimated 65.8 rem (658 mSv) to the noninvolved worker (approximately 66 percent of 100 rem (1 Sv) guideline), 5.2 rem (52 mSv) to the MEI (approximately 21 percent of 25 rem (250 mSv) guideline), and 116 rem (1.16 Sv) RH4-A, (approximately 116 percent of 100 rem guideline) to the immediate worker.

Evaluation of the Design Basis

For the purposed of establishing safety (safety-class or safety-significant) preventative and mitigative SSCs, an iterative process is performed. The safety (safety-class or safety-significant) iterative process involves comparing the "no-mitigation" accident consequences to the MEI and noninvolved worker (with associated "no-mitigation" accident frequency from the event tree analyses in Appendix D) to the off-site and on-site risk evaluation guidelines respectively. The process is continued taking credit for additional preventative/mitigative SSCs until the risk evaluation guidelines are met. Systems required to keep estimated consequences below the risk evaluation guidelines are designated as safety (safety-class or safety-significant) SSCs.

The accident analyses indicate that Design Class I (Safety Class) SSCs are not required for the WIPP to mitigate any MEI accident radiological and non-radiological consequence to below risk evaluation guideline levels. Secondary confinement is required to remain functional (following DBAs) to the extent that the guidelines in DOE Order O 420.1,[51] Section 4.1.1.2, Design Requirements, are not violated. The risk evaluation guidelines developed in this safety analysis report were used in the absence of definitive criteria DOE safety analysis orders or guidance documents for evaluation of secondary confinement. As previously stated, the MEI and noninvolved worker unmitigated consequences were found to be well below the selected risk evaluation guidelines, including accidents whose frequency is <1E-06/yr, and as such, secondary confinement is not required. However, existing Design Class II and IIIA secondary confinement SSCs, while not required to mitigate the consequences of an accident from exceeding the risk evaluation guidelines, support the second layer of the WIPP defense-in-depth philosophy.

As discussed in the accident scenarios in Section 5.2.3, there is no credible physical mechanism by which the accidents occurring in the WHB or the Underground will disable the respective ventilation or HEPA filtration systems. No releases are postulated requiring ventilation or HEPA filtration for the DBE and DBT scenarios. If a waste drum or canister breach occurs in the WHB during an operational accident, the release to the outside environment is mitigated by the permanently installed continuously on-line two-stage HEPA filter. For credible accident scenarios in the Underground (RH4-B and NC4), shift of the underground ventilation system may occur manually (it is assumed the CMR operator will be notified or be aware of the accident and actuate the shift to filtration), or automatically. No release scenarios are expected to be initiated during a DBE or DBT, primarily due to the DBE/DBT design of the WHB structure including tornado doors and specific waste handling equipment such as the WHB 6.25-ton grapple hoist and waste hoist. The WHB ventilation and filtration systems are not required to mitigate the consequences of the DBE or DBT scenarios.

Based on criteria in Chapter 3, Section 3.1.3.2, the factors that lead to designation of a component as Safety Significant are:

- SSCs whose preventive or mitigative function is necessary to keep hazardous material exposure to the noninvolved worker below on-site risk evaluation guidelines,

- SSCs that prevent acute worker fatality or serious injury from hazardous material release that is outside the protection of standard industrial practice, OSHA regulation, or MSHA safety regulation (e.g. potentially explosive waste containers).

As concluded from the Section 5.2, none of the analyzed scenarios (<u>all</u> scenarios are analyzed without regard for occurrence frequency) resulted in noninvolved worker consequences exceeding the risk evaluation guidelines. Therefore, there are no SSCs that are considered Safety Significant due to need to prevent or mitigate noninvolved worker consequence.

The 72-B HAZOP identified sixteen potential scenarios and the 10-160B HAZOP identified nine potential scenarios related to WIPP RH waste handling operations, that could result in worker fatality with no radiological release. They were identified as industrial hazards with no radiological release and will be covered under the WIPP's Operational Safety programs (Chapter 8). The 72-B HAZOP identified twelve potential scenarios and the 10-160B HAZOP identified five potential scenarios that could result in worker fatality and radiological release. Both HAZOPs identified one potential scenario that could result in worker fatality, waste hoist failure while transporting personnel. This event was evaluated in section 5.2.3.4. Personnel and waste containers will not be transported simultaneously. Failure of the waste hoist while transporting personnel does not constitute a process related accident involving radioactive materials and as such is considered a standard industrial hazard associated with standard mining operations. Hoisting operations are required to comply with the requirements of 30 CFR 57 and the New Mexico Safety Code for all Mines. For protection of the immediate worker, the waste hoist brake system is designated Safety Significant and specific Administrative Controls are derived in Chapter 6 and assigned in Attachment 1, Technical Safety Requirements.

Specific SSCs that fulfill a defense-in-depth safety function are: (1) the waste handling equipment such as the WHB 6.25-ton grapple hoist, diesel forklifts, Horizontal Emplacement and Retrieval Equipment (HERE), facility cask rotating device, waste-hoist, 140/25 ton crane, Hot Cell crane, PAR manipulator and (2) WIPP confinement SSCs including waste canisters and drums, 72-B cask, 10-160B cask, facility canister and facility cask, WHB and Underground structure, and WHB and Underground ventilation and filtration systems. With regard to waste handling equipment, in each instance their reliability and functionality are important to the prevention of damage to the waste containers (first layer of defense in depth). As such, their designation as defense-in-depth SSCs ensures that they are designed, maintained, and operated to prevent failure resulting in an accident. WIPP confinement SSCs (WHB and Underground ventilation and filtration systems, and WHB and Underground structure) support the second layer of defense-in-depth. All other WIPP SSCs are considered as balance of plant.

Specific WIPP SSCs are classified as defense-in-depth SSCs, based on the above functional classification results. Rather than the WIPP SAR specify functional requirements and performance criteria for those defense-in-depth SSCs, the applicable SDDs describe their intended safety functions, and specify the requirements for design, operation, maintenance, testing, and calibration.

As discussed in detail in Chapter 6, based on application of the criteria in 10 CFR 830.205 [52] for the selection of safety and operational limits, and the fact that Safety Class SSCs are not selected for WIPP, TSR Safety Limits (SLs), Limiting Conditions for Operation (LCOs), and Surveillance Requirements are not required. TSR ACs assigned for features discussed above that play a role in supporting the WIPP defense-in-depth approach are derived in Chapter 6. 10 CFR 830.205 and its implementation guide allow coverage of Safety Significant SSCs through Administrative Controls. Table 6-1 provides a summary of defense-in-depth safety features and applicable TSR controls.

Based on the fact that TSR Operational Limits and Surveillance Requirements are not defined for WIPP, operability definitions for Defense-in-Depth SSCs are not required in the SAR. SSCs are required in the TSR to be operated as required during each facility mode as described in Table 6-2, to support the overall WIPP defense-in-depth strategy.

Evaluation of Human Factors

A systematic inquiry of the importance to safety of reliable, correct, and effective human-machine interactions, considering the mission of the WIPP facility and the physical nature of the radioactive wastes that it will receive was conducted. [70] The specific human errors that can contribute to accidental releases of hazardous materials were evaluated as an integral part of each hypothesized accident. Based on the analysis of those accidents, it can be concluded that the WIPP WAC , facility design, and operational controls provide high confidence that all potential releases can be contained with passive safety features that eliminate the need for human actions requiring sophisticated human-machine interfaces.

To provide additional support for the conclusion that no detailed human factor evaluation of human-machine interfaces is required, a scoping assessment of the effectiveness of the human-machine interfaces that support important design functions of the Table 4.1-1 Design Class II and IIIA systems was performed. It can be seen in Table 4.8-1 that most of the Design Class II and IIIA WIPP systems and equipment do not require human actions to initiate or sustain their function relative to the release of radiological or non-radiological waste materials. In most cases these functions are accomplished with automatic passive mechanisms designed to provide containment for the waste materials.

Functions allocated to automatic passive mechanisms or automatic active systems may be influenced by human error during maintenance. However, using the graded approach, human-machine interfaces for maintenance activities at WIPP are judged to be adequate because they are deliberate, and there is ample opportunity to discover errors and correct them with no adverse safety consequences.

The ability of the staff to accomplish their responsibilities in potential accident environments was evaluated. The limited magnitude of the hazard and the lack of dispersal driving forces provide very high confidence that the staffing and training presented in those sections will enable the staff to perform their responsibilities in potential accident environments.

The magnitude of hazardous materials that can be involved in an accident leading to a release is very limited. The radioactive material is delivered to the site in closed containers, and the waste handling operations are designed to maintain that integrity throughout the entire process required to safely emplace those containers in the site's underground waste disposal rooms. Inventory limits on individual containers ensure that heat generated by radioactive decay can be easily dissipated by passive mechanisms. Finally, only a limited number of waste containers have the possibility of being breached as a result of any one accident initiating event. As a result, the consequences of unmitigated releases from all accidents hypothesized in Chapter 5, including those initiated by human error, do not produce significant offsite health consequences.

The facility has no complex system requirements to maintain an acceptable level of risk. The facility is designed to minimize the presence and impact of other energy sources that could provide the heat or driving force to disperse hazardous materials. When something unusual happens during normal operations, such as support systems becoming unavailable, **waste handling can be simply stopped** and personnel evacuated until an acceptable operating condition is reestablished.

Should an initiating event occur that breaches the waste containers, **the plant design permits the immediate cessation of activity and isolation of the area where the breach occurs.** Once isolation is achieved, there is no driving force within the waste or waste handling area that could result in a release of the waste material. Consequently, **sufficient time is available to thoroughly plan and prepare for the remediation process prior to initiating decontamination and recovery actions.**

Human factors considered in this SAR is limited to that time necessary to properly emplace the transuranic waste designated for disposal at WIPP. The operations will be straightforward, proceduralized, and consistent. Moreover, they will continue for only the period of time needed to complete the disposal process. Once a panel is filled and sealed off, the natural properties of the salt and the location of the mine combine to provide passive isolation of the waste from the environment. The potential for human intrusion after the facility closure is beyond the scope of the human factors evaluation considered here.

Conclusion

It is concluded from the hazards and accident analyses in this SAR that the design basis of the WIPP RH TRU waste handling systems are adequate in response to postulated range of RH TRU normal operations and accident conditions for the facility.

5.2.4.2 Analysis of Beyond the Design Basis Accidents

Operational Events

An evaluation of 72-B cask and 10-160B cask operational accidents "beyond" design basis accident (BDBA) is conducted to provide perspective of the residual risk associated with the operation of the facility. As discussed in DOE-STD-3009-94[1], BDBAs are simply those operational accidents with more severe conditions or equipment failure. Based on the analyses in Section 5.2.3, the operational accident scenario involving potential consequences to the non-involved worker, MEI, and immediate worker, whose frequency is less than 1E-06/yr is RH5, Fire followed by Explosion.

The source term MAR developed in Section 5.2.3 is based on the 72-B waste canister inventory derived in Section 5.1.2.1.2. The analyses assumed that based on the data in Appendix A, that the maximum radionuclide inventory in a 72-B waste canister is 80 PE-Ci for direct loaded waste and 240 PE-Ci for double contained waste. The on-site and off-site risk evaluation guidelines for the extremely unlikely range are used for the consequence evaluation even though the frequency of the BDBA scenarios is beyond extremely unlikely.

The worse case radiological consequences of RH5 are discussed here assuming that waste canister involved in the scenario is at 80 PE-Ci. The same assumptions regarding waste form combustible and noncombustible composition, damage ratio, airborne release fraction (median value instead of bounding), and respirable fraction are assumed. Substitution of these values into the consequence calculations for RH5, indicate doses of approximately 0.6 rem (6 mSv) to the noninvolved worker individual (less than one percent of the 100 rem noninvolved worker risk evaluation guideline for the extremely unlikely range), and 0.05 rem (.5 mSv) (less than one percent of 25 rem MEI risk evaluation guideline for the extremely unlikely range) to the MEI. The noninvolved worker and MEI doses are below their respective risk evaluation guidelines. The estimated 5.4 rem (54 mSv) dose to the immediate worker for the RH5 beyond design basis scenario (Appendix E, Table E-15) does not exceed the noninvolved worker risk evaluation guideline of 100 rem (1 Sv) for the extremely unlikely range. Therefore, no specific additional worker protection engineering or administrative controls are identified. The risk associated with this potential exposure is deemed acceptable for the following reasons:

- The conservatism in the risk evaluation guidelines as discussed in Section 5.2.2, as well as the application of the on-site guidelines to the immediate worker.
- The conservatism inherent in all of the accident analysis source term variables used to estimate the above consequences,
- The existing elements for protection of the worker discussed in detail in Section 5.1.7.

Natural Phenomena

As discussed in Section 3.4.3 of DOE-STD-3009-94[1], natural phenomenon BDBAs are defined by a frequency of occurrence less than that assumed for the DBA. Since the DBT is defined with a 10^{-6}/yr return period, and the DBE as a 10^{-3}/yr return period, the most credible BDBA natural phenomenon event is an earthquake with a vertical ground acceleration of greater than 0.1 g (considered extremely unlikely). DBE SSCs: (1) the WHB structure, and (2) WHB 140/25-ton bridge crane, the CUR 25-ton crane, the Hot Cell crane, and the Facility Cask Loading Room grapple hoist, are assumed to fail resulting in a release of radioactive material.

The source term MAR developed in Section 5.2.3 is based on the 10-160B road cask inventory derived in Section 5.1.2.1.2. The analyses assumed that based on the data in Appendix A, that the maximum radionuclide inventory in a 10-160B road cask is 20 PE-Ci.

It is assumed that the WHB structure fails resulting in the Hot Cell roof collapsing into the Hot Cell which damages 10 waste drums awaiting placement in facility canisters and a partially loaded facility canister. The partially loaded facility canister containing two drums from two different 10-160B casks is in the loading station. Each of the two drums in the facility canister contain the maximum radionuclide inventory of a 10-160B road cask. The total Hot Cell inventory is 60 PE-Ci. It is conservatively assumed that all of the drums and the partially loaded facility canister are breached by the falling Hot Cell roof debris and the Hot Cell crane. The beyond DBE is basically the same accident as described for NC3-F, with the same MAR, waste form combustible and noncombustible composition, airborne release fraction, and respirable fraction. Using the NC3-F values and a factor of 10 increase in the damage ratio, the consequence calculations for beyond DBE indicate doses of approximately 24.7 rem (247 mSv) to the non-involved worker (approximately 25 percent of the 100 rem non-involved worker risk evaluation guideline for the extremely unlikely range), and 1.9 rem (19 mSv) (approximately 7.6 percent of 25 rem MEI risk evaluation guideline for the extremely unlikely range) to the MEI. The non-involved worker and MEI doses are below the risk evaluation guidelines, respectively. There is no postulated dose to the immediate worker since the event occurs in the Hot Cell which would not be occupied during waste handling operations. Therefore, the radiological risk associated with a greater than 0.1 g earthquake is considered acceptable.

5.2.4.3 Assessment of WIPP Waste Acceptance Criteria (RH WAC)

RH WAC Pu-239 Equivalent Activity Operations and Safety Requirement

Based on the design basis accident analysis results in Section 5.2.3, the estimated radiological consequences for RH4-A, LOC in the Underground (waste hoist failure) to the immediate worker, and NC3, LOC in the WHB, to the noninvolved worker, are approximately equal to and both approach the respective accident risk evaluation guidelines. Therefore, the 80 PE-Ci for direct loaded and 240 PE-Ci for double contained 72B waste canisters and the 20 PE-Ci for the 10-160B cask derived in Section 5.1.2.1.2, are established as the RH WAC Pu-239 Equivalent Activity Operations and Safety maximum allowable waste container radionuclide inventories for RH TRU waste. The establishment of the above waste container radionuclide inventories values, provides a defense-in-depth based approach to ensure that the estimated immediate worker accident consequences from RH TRU waste remain acceptable.

Based on the beyond design basis accident analysis results in Section 5.2.4.2, the estimated radiological consequences for RH5, Fire Followed by and Explosion in the Underground, to the immediate worker, do not exceed the selected accident risk evaluation guidelines. Therefore, no specific additional worker protection engineering or administrative controls are identified. The risk associated with this potential exposure is deemed acceptable for the following reasons:

- The conservatism in the risk evaluation guidelines as discussed in Section 5.2.2, as well as the application of the on-site guidelines to the immediate worker,
- The conservatism inherent in all of the accident analysis source term variables used to estimate the above consequences,
- The existing elements for protection of the worker discussed in detail in Section 5.1.7.

The WIPP RH WAC Thermal Power waste canister requirements, limits the decay heat from all RH-TRU waste to 300 watts per waste canister.

The RH WAC Pu-239 Equivalent Activity Operations and Safety limits, when analyzed in conjunction with conservative safety analysis assumptions, and existing stored waste information: (1) provides a reasonable degree of assurance that the safety envelop of the facility has been defined, and (2) ensures that the risk to immediate workers, noninvolved worker, and the MEI remain well within the risk evaluation guidelines.

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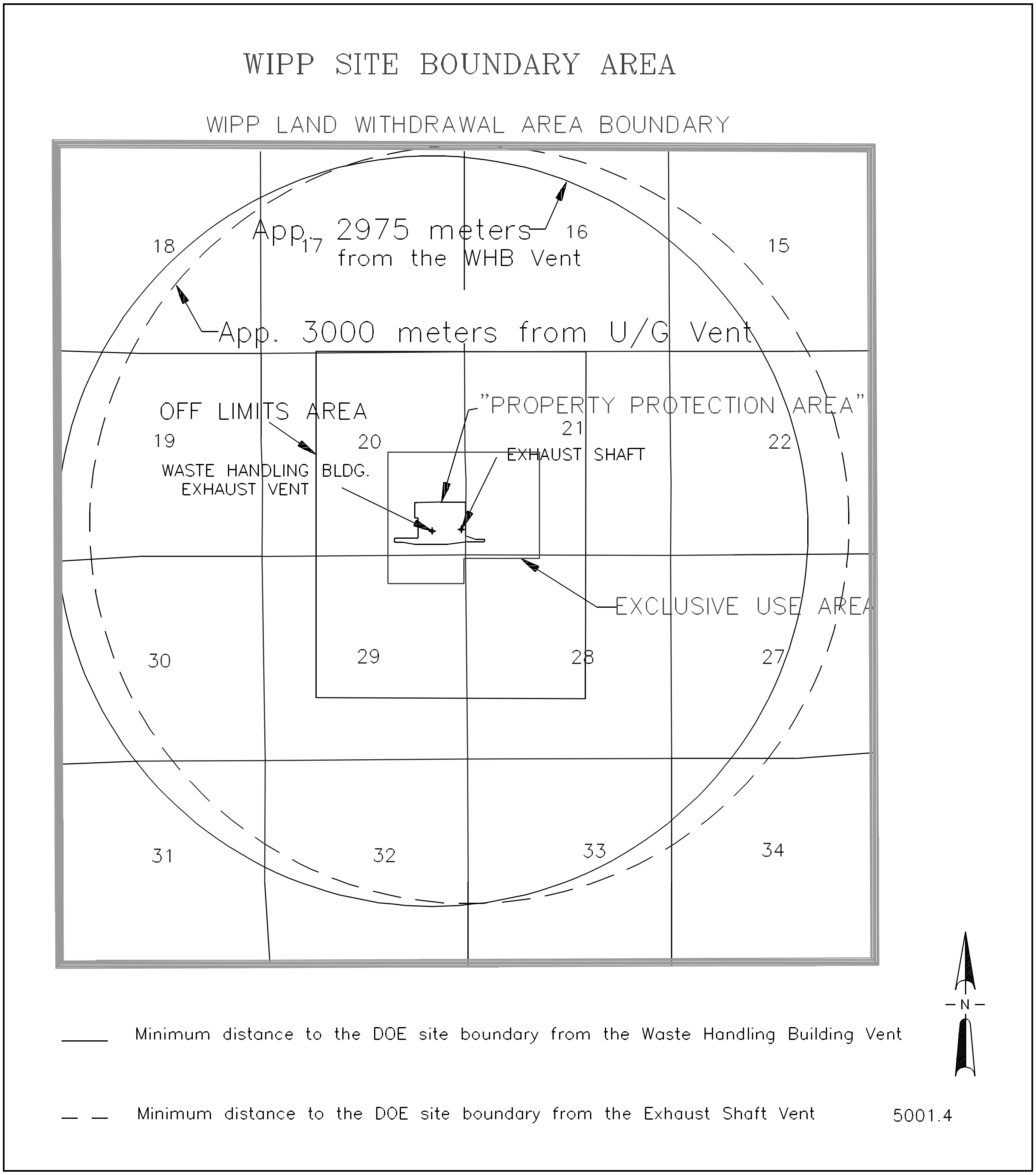

Figure 5.2-1, WIPP Site Boundary Area

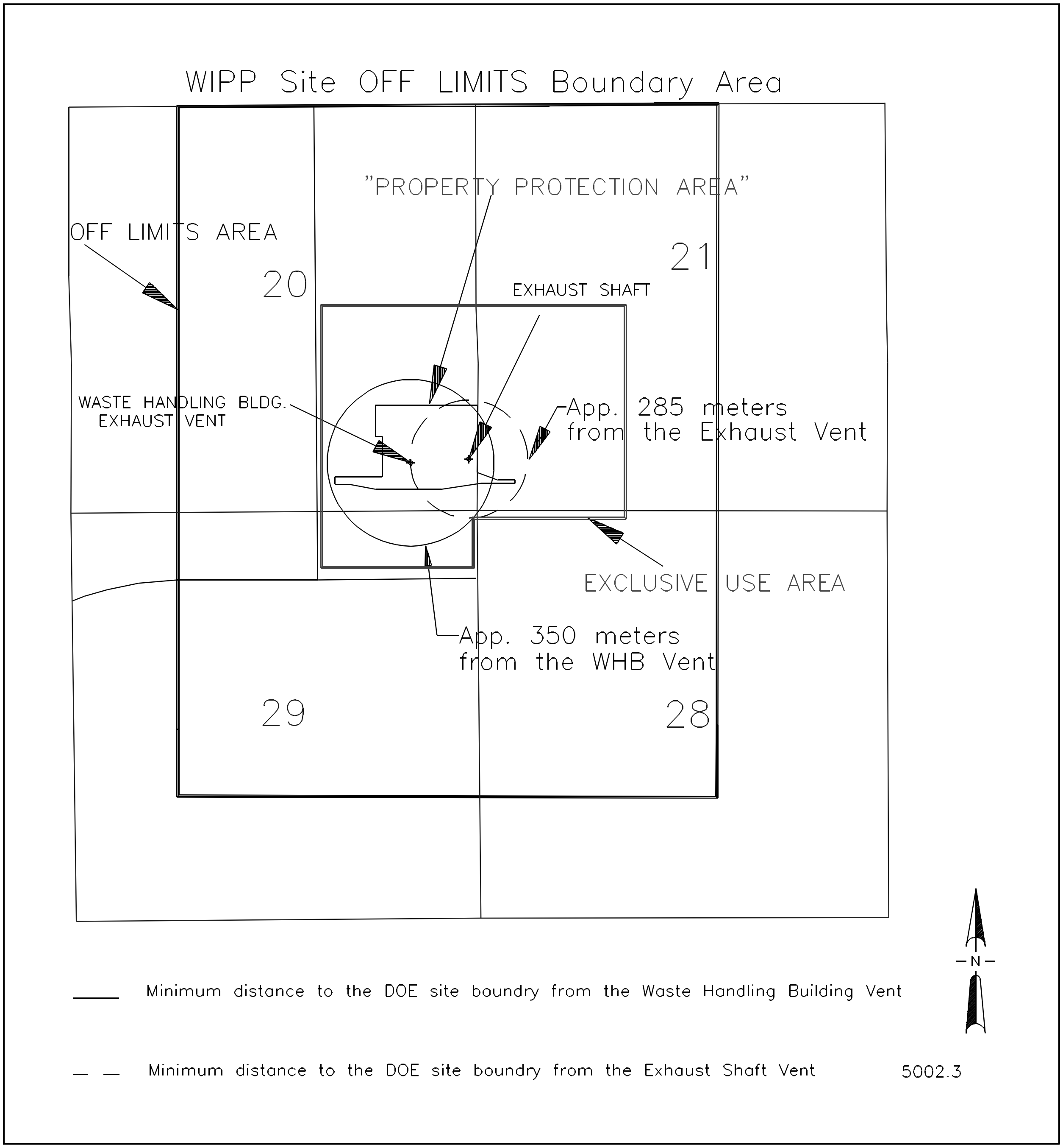

Figure 5.2-2, WIPP Site Off-Limits Boundary Area

Table 5.2-1a MEI Risk Evaluation Guidelines

Description	Estimated Annual Frequency of Occurrence	Description	Radiological Guidelines	Nonradiological Guidelines
Normal operations	$1 \geq f > 10^{-1}$			
Anticipated	$10^{-1} \geq f \geq 10^{-2}$	Incidents that may occur several times during the lifetime of the facility. (Incidents that commonly occur)	≤ 2.5 rem (25 mSv)	ERPG-1
Unlikely	$10^{-2} \geq f > 10^{-4}$	Accidents that are not anticipated to occur during the lifetime of the facility. Natural phenomena of this class include: Uniform Building Code-level earthquake, 100-year flood, maximum wind gust, etc.	≤ 6.5 rem (65 mSv)	ERPG-1
Extremely Unlikely	$10^{-4} \geq f > 10^{-6}$	Accidents that will probably not occur during the life cycle of the facility.	≤ 25 rem (250 mSv)	ERPG-2
Beyond Extremely Unlikely	$10^{-6} \geq f$	All other accidents.	No Guidelines	No Guidelines

Table 5.2-1b Noninvolved Worker Risk Evaluation Guidelines

Description	Estimated Annual Frequency of Occurrence	Description	Radiological Guidelines	Nonradiological Guidelines
Normal operations	$1 \geq f > 10^{-1}$			
Anticipated	$10^{-1} \geq f \geq 10^{-2}$	Incidents that may occur several times during the lifetime of the facility. (Incidents that commonly occur)	≤ 5 rem (50 mSv)	ERPG-1
Unlikely	$10^{-2} \geq f > 10^{-4}$	Accidents that are not anticipated to occur during the lifetime of the facility. Natural phenomena of this class include: Uniform Building Code-level earthquake, 100-year flood, maximum wind gust, etc.	≤ 25 rem (250 mSv)	ERPG-2
Extremely Unlikely	$10^{-4} \geq f > 10^{-6}$	Accidents that will probably not occur during the life cycle of the facility.	≤ 100 rem (1 Sv)	ERPG-3
Beyond Extremely Unlikely	$10^{-6} \geq f$	All other accidents.	No Guidelines	No Guidelines

Table 5.2-2 Toxicological Guidelines*

Substance	ERPG 1 - 2 - 3 (mg/m^3)	TEEL 1 -2 -3 (mg/m^3)
Asbestos	Not Available	1 - 0.3 2 - 1.0 3 - 500
Beryllium	1 - n/a 2 - 0.025 3 - 0.1	1 - 0.005
Cadmium	Not Available	1 - 0.03 2 - 4.0 3 - 9.0
Lead	Not Available	1 - 0.15 2 - 0.25 3 - 100
Butyl Alcohol	Not Available	1 - 150 2 - 150 3 - 4000
Carbon Tetrachloride	1 - 125 2 - 600 3 - 4000	
Mercury	1 - n/a 2 - 2.05 3 - 4.1	1 - 0.075
Methyl Alcohol	1 - 250 2 - 1250 3 - 6000	
Methylene Chloride	1 - 600 2 - 2500 3 - 12500	
Chloroform	1 - n/a 2 - 250 3 - 25000	1 - 10
1,1,2,2-Tetrachloroethane	Not Available	1 - 20 2 - 35 3 - 600
Trichloroethylene	1 - 500 2 - 2500 3 - 25000	
Polychlorinated Biphenyls (PCBs)	Not Available	1 - 3.0 2 - 5.0 3 - 5.0

* Values are from SCAPA's Revision 18 of ERPGs and TEELs for Chemicals of Concern - Table 4

Table 5.2-3a Summary of Noninvolved Worker and MEI Estimated Radiological Concentrations and Comparison to Guidelines [1]

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Accident	Unmitigated Release Freq/yr[2]	Noninvolved Worker /MEI Guidelines (rem)	Type of Release	Type of Loading	Receptor Dose (CEDE-rem) On-site (Non-involved Worker)	Receptor Dose (CEDE-rem) Exclusive Use Area Boundary (MEI)	Receptor Dose (CEDE-rem) Site Boundary	Receptor Dose % of Guidelines [(Dose/Guidelines)*100] On-site (Non-involved Worker)	Receptor Dose % of Guidelines Exclusive Use Area Boundary (MEI)	Receptor Dose % of Guidelines Site Boundary
RH4-A Loss of Confinement U/G (Waste Hoist)	Beyond Extremely Unlikely	100/25	Canister/ mitigated	Direct	1.46E-05	1.37E-06	9.44E-08	<1%	<1%	<1%
				Double Contained	4.38E-06	4.10E-07	2.83E-08	<1%	<1%	<1%
			Canister/ unmitigated	Direct	1.46E+01	1.37E+00	9.44E-02	15%	5%	<1%
				Doubled Contained	4.38E+00	4.10E-01	2.83E-02	4%	2%	<1%
RH4-B Loss of Confinement U/G (forklift)	Unlikely	25/6.5	Canister/ mitigated	Direct	5.84E-07	5.46E-08	3.78E-09	<1%	<1%	<1%
				Double Contained	1.75E-07	1.64E-08	1.13E-09	<1%	<1%	<1%
			Canister/ unmitigated	Direct	5.84E-01	5.46E-02	3.78E-03	2%	<1%	<1%
				Double Contained	1.75E-01	1.64E-02	1.13E-03	<1%	<1%	<1%
RH6 Seismic Event	Unlikely	25/6.5	Canister/ mitigated	Direct	No Release	No Release	No Release	N/A	N/A	N/A
				Double Contained	No Release	No Release	No Release	N/A	N/A	N/A
			Canister/ unmitigated	Direct	No Release	No Release	No Release	N/A	N/A	N/A
				Double Contained	No Release	No Release	No Release	N/A	N/A	N/A
NC1 Fire in the Hot Cell	Extremely Unlikely	100/25	Drum/ mitigated	Direct	8.23E-06	6.49E-07	4.84E-08	<1%	<1%	<1%
			Drum/ unmitigated	Direct	8.23E+00	6.49E-01	4.84E-02	8%	3%	<1%
NC3-A, NC3-B Puncture Drum or Canister Outside Hot Cell	Unlikely	25/6.5	Drum/ mitigated	Direct	1.64E-06	1.30E-07	9.67E-09	<1%	<1%	<1%
			Drum/ unmitigated	Direct	1.64E+00	1.30E-01	9.67E-03	7%	2%	<1%
NC3-C, NC3-E Dropped/ Puncture Drum in Hot Cell	Unlikely	25/6.5	Drum/ mitigated	Direct	8.22E-07	6.49E-08	4.83E-09	<1%	<1%	<1%
			Drum/ unmitigated	Direct	8.22E-01	6.49E-02	4.83E-03	3%	<1%	<1%
NC3-D Dropped Drum outside Hot Cell	Unlikely	25/6.5	Drum/ mitigated	Direct	4.11E-07	3.24E-08	2.42E-09	<1%	<1%	<1%
			Drum/ unmitigated	Direct	4.11E-01	3.24E-02	2.42E-03	2%	<1%	<1%

Table 5.2-3a Summary of Noninvolved Worker and MEI Estimated Radiological Concentrations and Comparison to Guidelines [1]

Page 2 of 2

Accident	Unmitigated Release Freq/yr[2]	Noninvolved Worker /MEI Guidelines (rem)	Type of Release	Type of Loading	Receptor Dose (CEDE-rem)			Receptor Dose % of Guidelines [(Dose/Guidelines)*100]		
					On-site (Non-involved Worker)	Exclusive Use Area Boundary (MEI)	Site Boundary	On-site (Noninvolved Worker)	Exclusive Use Area Boundary (MEI)	Site Boundary
NC3-F Puncture of Drum or Canister outside of Hot Cell	Unlikely	25/6.5	Drum/ mitigated	Direct	2.47E-06	1.95-07	1.45E-08	<1%	<1%	<1%
			Drum/ unmitigated	Direct	2.47E+00	1.95E-01	1.45E-02	10%	3%	<1%
NC4 LOC in Transfer Cell or U/G	LOC in Transfer Cell Bounded by RH3 which is Beyond Extremely Unlikely		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	LOC in U/G bounded by RH4-A (beyond extremely unlikely and RH4-B(unlikely)		same as RH4-B	same as RH4-B	N/A	N/A	N/A	N/A	N/A	N/A
NC7 Seismic Event	Unlikely	25/6.5	Drum/ mitigated	Direct	No Release	No Release	No Release	N/A	N/A	N/A
			Drum/ unmitigated	Direct	No Release	No Release	No Release	2%	<1%	<1%
NC8 Tornado Event	Extremely Unlikely	25/6.5	Drum/ mitigated	Direct	No Release	No Release	No Release	N/A	N/A	N/A
			Drum/ mitigated	Direct	No Release	No Release	No Release	N/A	N/A	N/A

Notes: (1) Listed accidents are those whose unmitigated frequency, as derived in Appendix D, is $>10^{-6}$/yr and accidents whose quantification of the active components caused the frequency exceed 10^{-6}/yr. The consequences of beyond extremely unlikely accidents may be found in the respective accident scenario or Appendix E.

(2) The unmitigated release frequency is as derived from the event tree (Appendix D)

1 REM = .01 Sv $1 mg/m^3 * 1.6E7 = 1 lb/ft^3$

Table 5.2-3b Summary of Immediate Worker Estimated Radiological Dose and Comparison to Guidelines [1] **Page 1 of 2**

Accident	Unmitigated Release Freq/yr[2]	Immediate Worker Guidelines (rem)	Type of Release	Type of Loading	Receptor Dose (CEDE-rem)	Receptor Dose % of Guidelines [(Dose/Guideline)*100]
RH4-A LOC in U/G (hoist)	Beyond Extremely Unlikely	100	Canister/ Unmitigated	Direct	1.16E+02	116%
				Double Contained	3.48E+01	34.8%
RH4-B LOC in U/G (forklift)	Unlikely	100	Canister/ Unmitigated	Direct	5.41E+00	5.41%
				Double Contained	1.62E+00	1.62%
RH6 Seismic Event	Unlikely	100	Canister/ Unmitigated	Direct	No Release	NA
				Double Contained	No Release	NA
NC1 Fire in the Hot Cell	Extremely Unlikely	100	Drum/ Unmitigated	Direct	No Immediate Worker Present	NA
NC3-A Puncture of drum inside Hot Cell	Unlikely	100	Drum/ Unmitigated	Direct	No Immediate Worker Present	NA
NC3-B Puncture of drum inside CUR	Unlikely	100	Drum/ Unmitigated	Direct	No Immediate Worker Present	NA
NC3-C, NC3-E Dropped or Punctured Drum in Hot Cell	Unlikely	100	Drum/ Unmitigated	Direct	No Immediate Worker Present	NA
NC3-D Dropped Drum/Canister outside Hot Cell (inside CUR or Transfer Cell	Unlikely	100	Drum or Canister/ Unmitigated	Direct	No Immediate Worker Present	NA
NC3-F Puncture of Drum or Canister outside of Hot Cell (inside Transfer Cell)	Unlikely	100	Drum or Canister/ Unmitigated	Drum Direct / Canister Double Contained	No Immediate Worker Present	NA

Table 5.2-3b Summary of Immediate Worker Estimated Radiological Dose and Comparison to Guidelines [1] **Page 2 of 2**

Accident	Unmitigated Release Freq/yr[2]	Immediate Worker Guidelines (rem)	Type of Release	Type of Loading	Receptor Dose (CEDE-rem)	Receptor Dose % of Guidelines [(Dose/Guideline)*100]
NC4 LOC in Transfer Cell or U/G	Extremely Unlikely	100 Transfer Cell	Canister / Unmitigated	Double Contained	No Immediate Worker Present in Transfer Cell	NA for Transfer Cell
		U/G Bounded by RH4-B			1.62E+00	1.62%
NC7 Seismic Event	Unlikely	100	Drum/ Unmitigated	Direct	No Release	NA
NC8 Tornado Event	Extremely Unlikely	100	Drum/ Unmitigated	Direct	No Release	NA

Notes: (1) Listed accidents are those whose unmitigated frequency, as derived in Appendix D, is $>10^{-6}$/yr and accidents whose quantification of the active components caused the frequency to exceed 10^{-6}/yr. The consequences of beyond extremely unlikely accidents may be found in the respective accident scenario.

(2) The unmitigated frequency is as derived from the event tree (Appendix D)

1 REM = .01 Sv

Table 5.2-4a Summary of Noninvolved Worker and MEI Estimated Nonradiological Concentrations and Comparison to Guidelines [1]

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Accident	Unmitigated Release Freq/yr [2]	Type of Release	Compound	Concentrations (mg/m^3)		Noninvolved Worker/MEI Guidelines (mg/m^3)	% of Guidelines	
				Noninvolved Worker Area	Exclusive Use Area		Noninvolved Worker Area	Exclusive Use Area
RH4-A, Loss of Confinement U/G (Waste Hoist)	Beyond Extremely Unlikely	Canister/ Unmitigated	Methylene Chloride	3.99E+00	3.74E-01	1.25E+04 / 2.50E+03	<1%	<1%
			Carbon Tetrachloride	7.38E+00	6.90E-01	4.00E+03 / 6.00E+02	<1%	<1%
			Chloroform	3.86E-01	3.61E-02	2.50E+04 / 2.50E+02	<1%	<1%
			1,1,2,2 Tetrachloroethane	2.02E-01	1.89E-02	6.00E+02 / 3.50E+01	<1%	<1%
RH4-B, Loss of Confinement U//G (forklift)	Unlikely	Canister/ Unmitigated	Methylene Chloride	4.00E+00	3.74E-01	2.50E+03 / 6.0E+02	<1%	<1%
			Carbon Tetrachloride	7.38E+00	6.90E-01	6.0E+02 / 1.25E+02	1.2%	<1%
			Chloroform	3.86E-01	3.61E-02	2.5E+02 / 1.0E+01	<1%	<1%
			1,1,2,2 Tetrachloroethane	2.02E-01	1.89E-02	3.5E+01 / 2.0E+01	<1%	<1%
RH6, Seismic Event	Unlikely	No Release	N/A	N/A	N/A	N/A	N/A	N/A
NC1, Fire in Hot Cell	Extremely Unlikely	Drum/ Unmitigated	Asbestos	1.01E-03	7.94E-05	5.00E+02 / 1.00E+00	<1%	<1%
			Beryllium	1.01E-05	8.00E-07	1.00E-01 / 2.50E-2	<1%	<1%
			Cadmium	1.45E-07	1.15E-08	9.00E+00 / 4.00E+00	<1%	<1%
			Lead	4.02E-04	3.17E-05	1.00E+02 / 2.50E-01	<1%	<1%
			Butyl Alcohol	1.45E-04	1.15E-05	4.00E+03 / 1.50E+02	<1%	<1%
			Carbon Tetrachloride	3.05E-04	2.40E-05	4.00E+03 / 6.00E+02	<1%	<1%
			Mercury	4.24E-05	3.34E-06	4.10E+00 / 2.50E+00	<1%	<1%
			Methyl Alcohol	3.87E-07	3.05E-08	6.00E+03 / 1.25E+03	<1%	<1%
			Methylene Chloride	1.94E-05	1.53E-06	1.25E+04 / 2.50E+03	<1%	<1%
			PCBs	4.11E-04	3.24E-05	5.00E+00 / 2.50E+00	<1%	<1%
			Trichloroethylene	1.89E-04	1.49E-05	2.50E+04 / 2.50E+03	<1%	<1%

Table 5.2-4a Summary of Noninvolved Worker and MEI Estimated Nonradiological Concentrations and Comparison to Guidelines

Page 2 of 3

Accident	Unmitigated Release Freq/yr [2]	Type of Release	Compound	Concentrations (mg/m^3)		Noninvolved Worker/MEI Guidelines (mg/m^3)	% of Guidelines	
				Noninvolved Worker Area	Exclusive Use Area		Noninvolved Worker Area	Exclusive Use Area
NC3-A, Puncture of drum in Hot Cell	Unlikely	Drum/ Unmitigated	Methylene Chloride	1.03E+01	8.14E-01	2.50E+03 / 6.00E+02	<1%	<1%
			Carbon Tetrachloride	1.90E+01	1.50E+00	6.00E+02 / 1.25E+02	3.2%	1.2%
			Chloroform	9.96E-01	7.86E-02	2.50E+02 / 1.00E+01	<1%	<1%
			1,1,2,2 Tetrachloroethane	5.20E-01	4.10E-02	3.50E+01 / 2.00E+01	1.5%	<1%
NC3-B, Drum Puncture in CUR	Unlikely	Drum/ Unmitigated	Methylene Chloride	5.16E+00	4.07E-01	2.50E+03 / 6.00E+02	<1%	<1%
			Carbon Tetrachloride	9.52E+00	7.51E-01	6.00E+02 / 1.25E+02	1.5%	<1%
			Chloroform	4.98E-01	3.93E-02	2.50E+02 / 1.00E+01	<1%	<1%
			1,1,2,2 Tetrachloroethane	2.60E-01	2.05E-02	3.50E+01 / 2.00E+01	<1%	<1%
NC3-C, Dropped drum/facility canister in Hot Cell	Unlikely	Drum/ Unmitigated	Methylene Chloride	2.06E+00	1.63E-01	2.50E+03 / 6.00E+02	<1%	<1%
			Carbon Tetrachloride	3.81E+00	3.00E-01	6.00E+02 / 1.25E+02	<1%	<1%
			Chloroform	1.99E-01	1.57E-02	2.50E+02 / 1.00E+01	<1%	<1%
			1,1,2,2 Tetrachloroethane	1.04E-01	8.21E-03	3.50E+01 / 2.006E+01	<1%	<1%
NC3-D, Dropped drum carriage inside CUR or facility canister inside Transfer Cell)	Unlikely	Drum or facility canister/ Unmitigated	Methylene Chloride	1.03E+01	8.14E-01	2.50E+03 / 6.00E+02	<1%	<1%
			Carbon Tetrachloride	1.90E+01	1.50E+00	6.00E+02 / 1.25E+02	3.1%	1.2%
			Chloroform	9.96E-01	7.86E-02	2.50E+02 / 1.00E+01	<1%	<1%
			1,1,2,2 Tetrachloroethane	5.20E-01	4.10E-02	3.50E+01 / 2.00E+01	1.5%	<1%

Table 5.2-4a Summary of Noninvolved Worker and MEI Estimated Nonradiological Concentrations and Comparison to Guidelines

Accident	Unmitigated Release Freq/yr [2]	Type of Release	Compound	Concentrations (mg/m^3)		Noninvolved Worker/MEI Guidelines (mg/m^3)	% of Guidelines	
				Noninvolved Worker Area	Exclusive Use Area		Noninvolved Worker Area	Exclusive Use Area
NC3-E, Drum Puncture in Hot Cell	Unlikely	Drum/ Unmitigated	Methylene Chloride	1.03E+00	8.14E-02	2.50E+03 / 6.00E+02	<1%	<1%
			Carbon Tetrachloride	1.90E+01	1.50E-01	6.00E+02 / 1.25E+02	3.1%	<1%
			Chloroform	9.96E-02	7.86E-02	2.50E+02 / 1.00E+01	<1%	<1%
			1,1,2,2 Tetrachloroethane	5.20E-02	4.10E-03	3.50E+01 / 2.00E+01	<1%	<1%
NC3-F, facility canister puncture inside Transfer Cell	Unlikely	Facility canister/ Unmitigated	Methylene Chloride	3.09E+00	2.44E-01	2.50E+03 / 6.00E+02	<1%	<1%
			Carbon Tetrachloride	5.71E+00	4.51E-01	6.00E+02 / 1.25E+02	<1%	<1%
			Chloroform	2.99E-01	2.36E-02	2.50E+02 / 1.00E+01	<1%	<1%
			1,1,2,2 Tetrachloroethane	1.56E-01	1.23E-02	3.50E+01 / 2.00E+01	<1%	<1%
NC4, facility canister LOC in Transfer Cell or in U/G	LOC in Transfer Cell Beyond Extremely Unlikely	Facility canister/ Unmitigated	LOC in Transfer Cell same consequences as RH3					
	LOC in U/G Extremely Unlikely	Facility canister/ Unmitigated	LOC in U/G same consequences as RH4-B)					
NC7, Seismic Event	Unlikely	No Release	NA	NA	NA	NA	NA	NA
NC8, Tornado Event	Extremely Unlikely	No Release	NA	NA	NA	NA	NA	NA

Notes: (1) Listed accidents are those whose unmitigated frequency, as derived in Appendix D, is $>10^{-6}$/yr and accidents whose quantification of the active components caused the frequency exceed 10^{-6}/yr. The consequences of beyond extremely unlikely accidents may be found in the respective accident scenario and Appendix E.

Table 5.2-4b Summary of Immediate Worker Estimated Nonradiological Concentrations and Comparison to Guidelines[1]

Page 1 of 2

Accident	No-mitigation Freq/yr	Compound	Noninvolved Worker Guidelines (mg/m^3)*	Concentration (mg/m^3	% of Guidelines
RH4-A, Loss of Confinement U/G (waste hoist)	Beyond Extremely Unlikely	Methylene Chloride	1.25E+04	3.17E+01	< 1%
		Carbon Tetrachloride	4.00E+03	5.85E+01	1.5%
		Chloroform	2.50E+04	3.06E+00	< 1%
		1,1,2,2 Tetrachloroethane	6.00E+02	1.60E+00	< 1%
RH4-B, Loss of Confinement U//G (forklift)	Unlikely	Methylene Chloride	1.25E+04	3.70E+01	< 1%
		Carbon Tetrachloride	4.00E+03	6.83E+01	1.7%
		Chloroform	2.50E+04	3.57E+00	< 1%
		1,1,2,2 Tetrachloroethane	6.00E+02	1.87E+00	< 1%
RH6, Seismic Event	Unlikely	No release	N/A	N/A	N/A
NC1, Fire in Hot Cell	Extremely Unlikely	No immediate worker in Hot Cell	N/A	N/A	N/A
NC3-A, Puncture of drum in Hot Cell	Unlikely	No immediate worker in Hot Cell	N/A	N/A	N/A
NC3-B, Drum Puncture in CUR	Unlikely	No immediate worker in CUR	N/A	N/A	N/A
NC3-C, Dropped drum/facility canister in Hot Cell	Unlikely	No immediate worker in Hot Cell	N/A	N/A	N/A
NC3-D, Dropped drum carriage inside CUR or facility canister inside Transfer Cell	Unlikely	No immediate worker in Transfer Cell or CUR	N/A	N/A	N/A

Table 5.2-4b Summary of Immediate Worker Estimated Nonradiological Concentrations and Comparison to Guidelines

Page 2 of 2

Accident	No-mitigation Freq/yr	Compound	Noninvolved Worker Guidelines (mg/m^3)*	Concentration (mg/m^3	% of Guidelines
NC3-E, Drum Puncture in Hot Cell	Unlikely	No immediate worker in Hot Cell	N/A	N/A	N/A
NC3-F, facility canister puncture inside Transfer Cell	Unlikely	No immediate worker in Transfer Cell	N/A	N/A	N/A
NC4, facility canister LOC in Transfer Cell or in U/G	Beyond Extremely Unlikely	No immediate worker in Transfer Cell	N/A	N/A	N/a
	Extremely Unlikely	LOC in U/G same consequences as RH4-B	See RH4-B	See RH4-B	See RH4-B
NC7, Seismic Event	Unlikely	No Release	N/A	N/A	N/A
NC8, Tornado Event	Extremely Unlikely	No Release	N/A	N/A	N/A

Notes: (1) Listed accidents are those whose unmitigated frequency, as derived in Appendix D, is >10^{-6}/yr and accidents whose quantification of the active components caused the frequency exceed 10^{-6}/yr. The consequences of beyond extremely unlikely accidents may be found in the respective accident scenario and Appendix E.

* EPRG-3 values used for all frequencies

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5.3 Long-Term Waste Isolation Assessment

Applicable regulations require the DOE to demonstrate the ability of the WIPP repository to isolate TRU wastes for a 10,000-year period (40 CFR 191[1]). To evaluate the long-term performance of the disposal system, the DOE uses a technique developed especially for predicting the behavior of geologic repositories over the thousands of years required for waste isolation. This technique is performance assessment which is a multi disciplinary, iterative, analytical process that begins by using available information that characterizes the waste and the disposal system (the design of the repository, the repository seals, and the natural barriers provided by the host rock and the surrounding formations). The DOE uses performance assessment to estimate the releases of radionuclides, based on the probabilities of these relevant FEPs occurring. Sensitivity analyses are used by the DOE to determine which characteristics of the disposal system exert the greatest effect on performance. The results of performance assessment are used by the DOE in the 40 CFR Part 191 compliance program to assess the disposal system's behavior and the possible environmental releases.

The DOE's methodology for performance assessment uses relevant information about the disposal system and the waste to simulate performance over the regulatory time periods. This process is schematically represented by the flow diagram in Figure 5.3-1, which shows how information describing the disposal system is used by the DOE to develop scenarios, scenario probabilities, and the consequence models used to estimate performance. The WIPP performance assessment methodology has been reviewed by the NAS, the EEG, and experts in and outside the United States. Initially, the DOE used the process in Figure 5.3-1 with a feedback line from the Uncertainty Analysis block to the System Description block. In this way, the DOE used performance assessment to identify important parameters and the programs needed to better define the parameters and to obtain relevant information.

Uncertainty and how it is handled in the analysis plays a major role in the formulation of a performance assessment strategy. The EPA anticipates that uncertainty in long-term predictions will be inevitable and substantial (see 40 CFR § 191.13(b)). Because of this, the Agency applies a reasonableness test to the outcome of performance assessments. In other words, the uncertainty that is inherent in modeling the behavior of natural and engineered system is such that there is likely no single correct set of models and assumptions. Instead, there are those models and assumptions that lead to a "reasonable expectation" that compliance will be achieved.

The DOE has addressed uncertainty associated with the WIPP disposal system through careful site, facility, and waste characterization. Uncertainty remaining after these characterizations is incorporated into the performance assessment through the use of reasonable assumptions about models and parameter distributions.

In general, the DOE has not attempted to bias the performance assessment toward a conservative outcome, the mean CCDF represents a best estimate of the expected, and in the case of human intrusion, prescribed performance of the disposal system. However, where realistic approaches to incorporating uncertainty are unavailable or impractical, and where the impact of the uncertainty on performance is small, the DOE has chosen to simplify the analysis by implementing conservative assumptions. The conservatism in the analysis does not significantly affect the location of the mean CCDF in Figure 5.3-2 (DOE/CAO-1996-2184, Title 40 CFR Part 191, Compliance Certification Application for the Waste Isolation Pilot Plant, October 1996[2]).

References for Section 5.3

1. 40 CFR 191, Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Wastes, Subpart A, Environmental Standards for Management and Storage.

2. DOE/CAO-1996-2184, Title 40 CFR Part 191, Compliance Certification Application for the Waste Isolation Pilot Plant, October 1996.

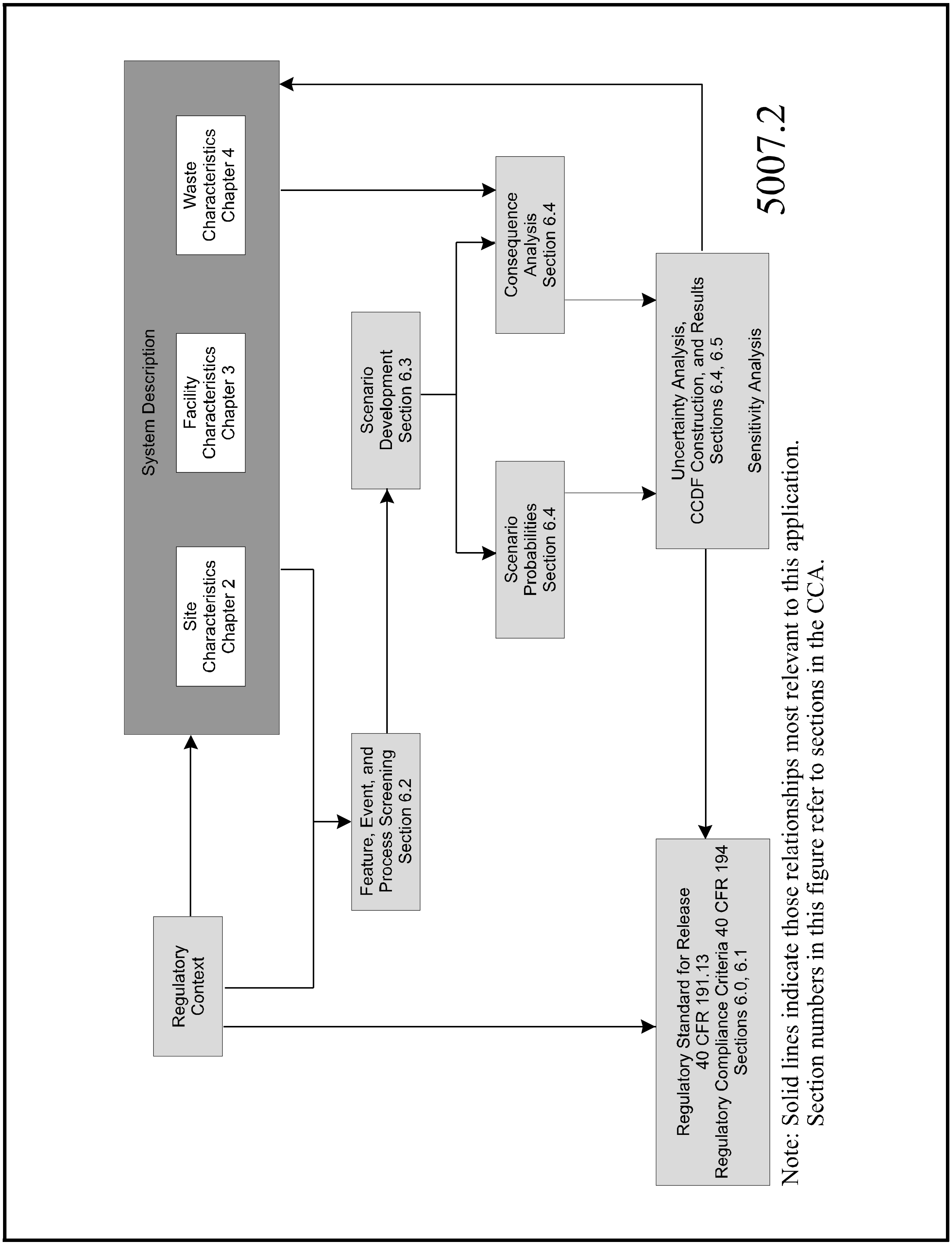

Figure 5.3-1, Methodology for Performance Assessment for the WIPP

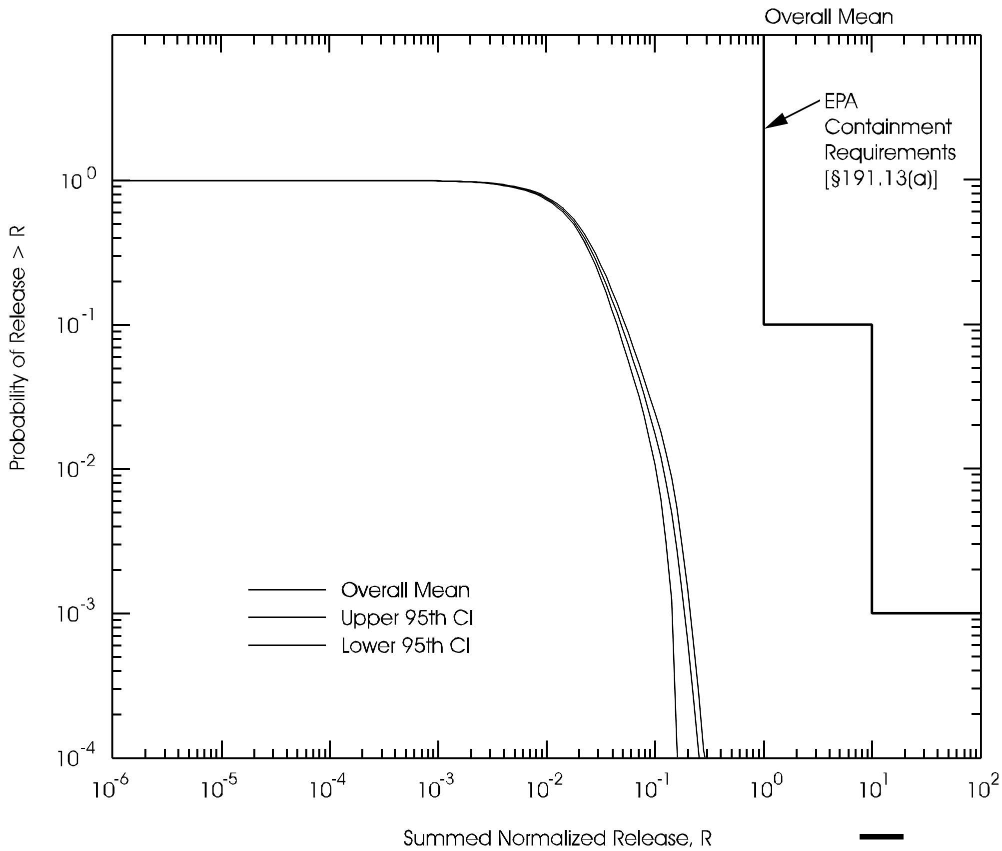

Figure 5.3-2, Final WIPP CCDF

5.4 Conclusions

The analyses in this chapter provide a detailed review of the potential hazards associated with RH TRU waste handling operations. The methodologies used in this process included qualitative hazard analysis and a quantitative evaluation of the potential consequences of postulated accidents. The hazard analysis process indicated that seven potential accident scenarios required further review and quantitative evaluation. Based on bounding canister inventory and release estimates, the calculated accident consequences were compared to accident risk evaluation guidelines for the public and found to be significantly below the guidelines.

Additionally, (1) the analysis indicated safety class or safety significant SSCs are not required for the WIPP to mitigate any accident radiological and non-radiological consequence to below risk evaluation guidelines, and (2) per the discussion in Section 4.4.1, secondary confinement is not required. Defense-in-depth SSCs while not required to prevent or to mitigate the consequences of an accident from exceeding the risk evaluation guidelines support the WIPP defense-in-depth philosophy.

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